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STOPPING AND BACKING TESTS U. S. COAST GUARD CUTTERS *DUANE* AND *CAMPBELL.*

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The performance of a vessel during the transient conditions of stopping and backing is of particular interest to the naval designer. In this article the author uses data obtained from the trials of recent Coast Guard vessels. He develops conclusions in regard to the importance of "timing" in maneuvering the machinery and recommends certain principles of design to improve the time elements. Since ships' propellers are in an extreme state of cavitation during the stopping period, he has recognized the difficulty of evaluating the effect of water circulation in predicting

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full scale performance from model tests in open water or in a confined stream at reduced pressure. A wealth of detail is included regarding methods of test and sources in order that the reader may appraise the accuracy of data and the applicability of the conclusions to a particular problem. Reference is made to articles on the stopping of ships by Rear Admiral S. M. Robinson, U. S. Navy, in previous issues of the JOURNAL.

The vessels on which these tests were run are sister ships having the following characteristics: Length on water line 308′, beam 41′, mean draft 12′ 4″, displacement during tests 2350 tons, twin screw, 5300 S.H.P. at 20 knots. Propellers: three bladed, diameter 9′, pitch 10.135′, p/d = 1.126, M.W.R. = .315, B.T.F. = .045, PA ÷ DA = .41. The designed submergence to center line of shaft is 7.9′. The turbines are of the Westinghouse cross compound combination type with solid rotors, driving through a double reduction gear giving a total reduction of 23.44 to 1 for the H.P., and 17.7 to 1 for the L.P. turbine. An astern turbine is built into each L.P. ahead casing. The astern turbine consists of two impulse stages each having two moving rows and one stationary row of blading. Each astern turbine has the H.P. nozzles divided into two equal groups supplied through separate astern steam lines and provided with valves so that one group can be closed when full boiler power is not quickly available, as at cruising speeds with small burners in use. The designed astern power at 204 R.P.M. is 60% of the full ahead power. The designed astern torque is 75% of full ahead torque at 80% of full ahead R.P.M. Model test curves are shown in Figures 1 and 1a. Actual test data from standardization runs and power trials is shown in Figure 1b. Figure 2 gives propeller curves from model tests.

On the *Campbell*, tests were run to obtain data on comparative time of stopping vessels by using first both sets of astern nozzles (60% of designed full ahead power), then only a single set (30% of designed power).

An endeavor was made to obtain simultaneous readings of torque, shaft R.P.M., and astern steam pressure by observers who took readings on a bell signal sounded at five second intervals. The ship's officers attempted to obtain data for a space-time curve

by sextant angles taken between the horizon and a floating object from the crow's nest. The space-time data were inconsistent and discrepancies were evident in data taken by observers.

The results of these tests are summarized in Figures 3 to 7, inclusive. In the tests an attempt was made to stop the turbines as quickly as possible. The astern throttle was opened first slightly, then the ahead throttle closed as the astern throttle was opened simultaneously. It is believed that the small difference in time required to stop the turbines when using one nozzle group over that required when using both may be due to the astern steam pressure building up more rapidly with one nozzle group in use. The time interval required to close the ahead throttle and open the astern throttle is appreciable. In later tests in which the ahead throttle was closed before the astern throttle was opened, more than 20 seconds elapsed between the astern bell and 250 lb. on astern chest.

It may be noted that in each case the torque curves drop over part of the time while revolutions are increasing. This would seem to indicate great cavitation. The appearance of the propellers tended to confirm this as under certain favorable conditions of light the propellers appeared as a white disk.

As noted on the curves of certain runs, steam was throttled when pronounced vibration was noted at the operating platform. This appears to occur about the end of the period of decreasing torque. Apparently the greatest vibration was not at the point of greatest cavitation, but at the end of this period when the propellers were perhaps beginning to establish a circulation and obtain solid water from the after side.

It was very difficult to obtain accurate torsionmeter readings during the time torque was falling to zero or changing rapidly. The points shown are the readings obtained but should be considered somewhat questionable.

The data, while questionable regarding distance through the water, appears to justify the conclusion that the time interval between giving an astern bell at 20 knots, and bringing the vessel to a relatively slow speed through the water is practically the same with one or both nozzle groups in use, and that an appreciable part of the time required to stop the propeller is used in operating

the present type of maneuvering valve, even when ahead and astern throttles are operated simultaneously.

The results of the tests on the *Campbell* appeared to justify a more comprehensive series of tests to check the first results. Unfortunately no method of obtaining torque or thrust directly was available on the tests of the *Duane*. Therefore an attempt was made to obtain data for constructing an accurate space-time curve from which propeller thrust could be studied with a view to deriving a formula to show the maximum power that could be used effectively on any given propeller and vessel while stopping the vessel from full speed.

Tests were made incidental to official acceptance trials, with no time properly to rehearse observers and operating personnel. The first trials on the *Campbell* had shown the necessity of eliminating the personal element in recording simultaneous readings of rapidly changing transient data. Therefore, arrangements were made to photograph the necessary instruments with 16 M.M. moving picture cameras in the engine room and at a range finder, and as an additional check, to photograph the bridge tachometers with a Leica miniature camera when engine room telegraphs were first moved to astern and at 8 to 10 second intervals thereafter until the vessel was dead in the water. The pictures of the main gauge board and of the bridge tachometer gave the required data in most instances when examined with the aid of a viewing lens. With the experience gained in these trials, consistent good results should be expected hereafter in recording data photographically with proper equipment.

An attempt was made to obtain the time-space data by heading toward a light ship from sufficient distance to give a steady ship's speed and operating conditions, then going astern at a safe distance of around 2000 yards while taking and recording the greatest practicable number of readings, with corresponding times, of the range to the light ship. A 2½ meter range finder was used.

Times of the readings at the various stations were coordinated by using synchronous electric clocks with enlarged second hands located so as to be photographed together with the readings of the instruments. The time error introduced by using the ship's 60-cycle current was found to be negligible for the period of the tests.

There was some doubt as to the feasibility of reading the range finder scale from photographs, due to the small size of the figures and lack of sufficient illumination. Hence, an attempt was made to record this range-time data with observers in addition to the moving picture camera. This proved a wise precaution since none of the films of range finder data proved legible. However, it is believed that, profiting by this experience, a legible photographic record of this data can be obtained in future tests.

The range finder party consisted of the following: The gunner at the eyepiece who called "mark" each time he brought the images into coincidence. A gunner's mate at the training eyepiece who kept the vertical crosswire on the mast of the light ship and who read the internal scale immediately after each "mark." An observer who noted the time of the nearest second from the electric clock at "mark" and repeated this time reading to a recorder immediately after the range was read. A fifth man who photographed the outside scale and electric clock with a 16 M.M. motion picture camera. The time-range data proved rather disappointing. This may be due to the instruments not having been calibrated, to personnel, or to variable time errors between the time images were matched and the time the clock was read. On some runs the vessel yawed due to a difference in propeller R.P.M. to such an extent that no readings could be obtained near the end of the run. Readings were still decreasing very slowly on many runs when engines were stopped from the bridge because the ship appeared to be dead in the water by observation and by standimeter readings. The mean line of approach usually plotted as showing up to 10% greater speed than that corresponding to the R.P.M. indicated by tachometers. An attempt to obtain an independent set of data as a check by a Dutch log scheme of throwing overboard and timing wood blocks between points along the ship's side gave results too inconsistent to be of value.

In plotting the time-range points a curve should be obtained which is tangent to a sloping straight line which represents the rate of approach at a point corresponding to the beginning of deceleration. Thence the curve rises to be tangent to a line parallel with the time axis at the point where the vessel is dead in water, then again rising if the vessel gathers sternway. As the slope of

this time-range curve represents rate of change of distance or speed, the slope obviously should decrease from the approach line to zero at the point of tangency at smallest range. Applying this reasoning to the plotted points at once shows inconsistencies in the range finder-time data, as simply fairing a curve through the plotted points will in most cases give a reverse curve at some point, thus indicating that the speed of the vessel decreases then increases again in the process of stopping, an impossible condition with steam on the astern turbines only. Stadimeter readings were thrown out as being more inconsistent than range finder readings. Space-time curves were faired through the plotted points of the range finder time data as well as possible while remaining tangent to the approach line and avoiding reverse curvature.

Realizing the error that would be thrown into the propeller thrust curve, which is calculated from the second derivative of the space-time curve, by slight changes in the original data, it would appear a waste of time to proceed further with the analysis of such questionable basic data. However, a rough graphic differentiation of the space-time curve was made giving the velocity-time curve of knots. This was treated in the same way to give the acceleration, from which a curve of total force acting was calculated. The difference between this curve and the curve of hull resistance from model test was assumed to give a curve of propeller thrust. The curves are to be taken as approximations only. The results are shown in Figures 8-19, inclusive.

The following is the derivation of the curves in more detail. Increments of the range for ten second intervals were taken from the faired space-time curve. As 1 knot = 101.33 feet per minute = .563 yards per second, the mean speed in knots = the change in range (δR) in the 10 seconds $\div$ 5.63 = .1776δR which was plotted as a point on the velocity curve. In some curves a second set of points half way between the first were obtained in a similar manner and velocity curve plotted between them.

Now having velocity as a function of time, acceleration $a = \frac{dv}{dt}$ and the total accelerating force acting $F = \frac{aw}{g}$. Expressing the

acceleration as the change of velocity in knots during a 10 second interval (δV) and using the displacement of the ship (2350 tons) gives: $F = \frac{V}{10} \times \frac{101.33}{60} \times \frac{2350}{3216} = 12.33\delta V$ tons. This retarding force (F) must be also the difference between the resistance of the hull (R) and the thrust of the propeller (T) when the ahead propeller thrust is considered plus T, since at a steady speed of 20 knots the accelerating force is zero and $T - R = O$, while when backing acceleration is negative and decelerating force $(-F) = (-T - R)$. When first applying astern steam the propeller thrust is positive, this falls to zero at the point where $F = R$, then becomes negative where F is greater than R.

The points on the curve of R were plotted from model tank test curves of E.H.P. of hull with appendages converted to tons thrust by the formula: $\frac{(E.H.P.) \times 33{,}000}{V \times 101.33 \times 2240} = T$ in tons, where V is taken from the corresponding point on the derived V curve of speed in knots. As no data were conveniently available on E.H.P. below 10 knots, the R curve was "guessed in" from 10 knots to zero by assuming R varied as about V^2.

The area under the time-acceleration curve obviously must equal the change in velocity and must be a constant for stopping the ship from a given speed in a given time, but the distance through the water will vary with the distribution of this area. In other words, a high resistance early in the stopping period will reduce the average speed and the distance travelled through the water. To illustrate this point further, suppose in the first case that the 2350 ton vessel is acted upon by a constant total retarding force of 26 tons which is approximately equal to the resistance at 20 knots. The speed of the vessel will drop at a uniform rate of $\frac{26}{2350} \times \frac{32.16}{1.689} = .211$ knots per second stopping after $\frac{20}{.211} = 95$ seconds. The velocity-time curve of course is a straight line. Distance covered $= V_o - \frac{1}{2}at^2$ or $\frac{1}{2}Vt$ to zero velocity. Initial velocity $V_o = 33.78$

ft. per second. Negative acceleration $= \frac{23 \times 32.16}{2350} = .356$ ft. per second, time $= 95$ seconds, distance $= 33.78 \times 95 - \frac{.356 \times 95^2}{2} =$ 1603 ft. approximately. The resulting velocity and space-time curves are (V) and (S) of Figure 21. Now suppose it is possible to stop this same vessel from the same speed by applying a retarding force of 78 tons for the first 25 seconds followed by a force of 7.39 tons for 70 seconds and in the third case reverse the order of application of the forces, first applying the retarding force of 7.39 tons for 70 seconds then a force of 78 tons for 25 seconds. The vessel will have been brought to rest in the same time in each case but the respective distances and velocity curves are as shown by Figure 21. With the large force applied first the vessel goes 777 ft. With the small force applied first the vessel goes 2470 ft. through the water. The major reason for fitting more than a small percentage of astern power in a relatively high powered vessel is presumably for added safety, in the hope of being able to stop quickly in case of emergency. Consideration would show that total time to dead in water is of less importance for safety than distance through the water and especially the initial rate at which speed is reduced. Suppose a collision to occur 40 seconds after the retarding force has been applied in the above example. The vessel will have a velocity of 11.6, 3.35, or 17.6 knots at time of collision depending upon which combination of retarding forces has been applied.

Now at 20 knots or 33.78 ft. per second a 20 second delay before revolutions begin to drop will mean 675.6 ft. covered at a rate of 20 knots in addition to any distance required to stop after power is reduced. Obviously net propeller thrust must equal resistance for steady operation up to the time of the break in the revolution curve, and if steam could be instantly shut off at the turbines the retarding torque would equal the full ahead torque acting at that instant less the torque developed by the steam in the turbines. The turbine blade torque would probably drop to a negative value in a small part of a second. This high propeller torque accounts for the sharp break in the R.P.M. curves occurring before ahead steam

pressure is greatly reduced. The propeller would exert a decreasing retarding torque as slip decreased and as the vessel slowed down, presumably exerting little torque at around the point of zero actual slip calculated from the *effective* propeller pitch. During this period energy is being applied to the propeller from the momentum of turbines and gears and until actual face slip becomes around 7% negative for these propellers, the propeller is exerting an ahead thrust on the vessel. Equally obviously, anything done to reduce the time required to slow the propeller to 7% negative slip will reduce the time to dead in water and will shorten the distance through the water more than time is shortened. During this period on a geared turbine installation a high astern turbine torque, say, several times full ahead torque, could be effectively used in slowing machinery without any of this torque being transmitted through gears or shafting to the propeller, the exact amount depending on the distribution of the total moment of inertia of the rotating system. After the propeller reaches zero slip and before revolutions reach zero, the torque transmitted through the shaft will be the torque required by the action of the water on the propeller less the torque being developed in slowing the propeller. It would appear that at no time until the propeller reaches zero speed can the shaft torque or propeller blade stress exceed that due to the action of the water on the propeller, or quite equal that of dragging a locked wheel at corresponding hull speeds. After slip becomes negative, propeller thrust reverses and tends to stop the vessel. Propeller torque reverses and tends to drive the turbines in the ahead direction. Neglecting friction and rotational losses, down to the point of zero slip the combined effect of propeller torque and such astern turbine torque as is being developed tends to slow turbines and gears. After the propeller speed falls below the point of zero slip the difference between the two torques is acting to slow the turbines, then accelerate them in the astern direction. The slope of the R.P.M.-time curve indicates the rate of change of momentum of rotating masses and obviously is a measure of the net force acting on the rotating masses. No great change in slope of the R.P.M. curves is apparent before zero R.P.M., thus showing that in these trials astern turbine torque builds up with steam pressure as ahead propeller torque drops to zero and then reverses (the rate at which the particular design of tachometer could respond may

have influenced the apparent results). After passing zero speed, astern propeller torque increases while, with a constant astern steam pressure, astern turbine torque would be expected to fall from a maximum value of about 1.6 times full ahead torque when astern turbine is still turning ahead against the steam at near full speed ahead R.P.M. to the rated value which in this case was 60% ahead power at 204 R.P.M. astern, or approximately 75% of full ahead torque at 80% of full ahead R.P.M. astern.

Had actual propeller torque curves been of the shape generally assumed, *i.e.*, showing a high negative torque peak at, say, 35% ahead R.P.M., a decided increase in slope of the R.P.M.-time curve would have been expected at just past this point due to the decreasing propeller torque, thus leaving more astern turbine blade torque available for deceleration of the rotating masses. The mistake is sometimes made of assuming that astern turbine blade torque or motor torque must always equal propeller torque. Obviously this can only be true if speed is constant. Either can be the greater. The difference in torques becomes available as an accelerating or decelerating force and the amount of this difference is indicated by the slope of the R.P.M. curve, with decreasing slope indicating slower rate of change in speed, thus less torque available for deceleration. In these tests the time-R.P.M. curves are believed accurate as far as indicating very closely the instantaneous reading of the tachometers. The slope of the R.P.M. curves of the Duane are believed to be more significant than the erratic torque readings obtained on the *Campbell* during the period of rapidly varying torque.

Torque curves plotted against R.P.M. are useful in attempts to show how propeller torque varies with R.P.M., but the area of such a curve has no significance as a measure of power or of energy. Each point of such a curve shows the force acting and the velocity at which this force is acting and thus represents a definite rate at which energy is being absorbed or expended but gives no measure of the amount since it does not indicate time or distance. For instance, a propeller is absorbing energy from the water while turning ahead at all values of negative thrust. A point may show 40% ahead R.P.M. at 60% negative torque. This indicates that 24% of full ahead power is being taken from the propeller and

absorbed in heating the squirrel cage winding of a main motor, but does not indicate the total amount of energy absorbed unless used with the time-R.P.M. curve. Obviously a propeller which slows from minus 7% slip to zero speed in one revolution collects a very small per cent of the energy absorbed by one which follows the same torque-R.P.M. curve but takes 100 revolutions to come to rest from minus 7% slip. In other words the quicker the deceleration through this range the less heat is put into the system of a turbo-electric plant, or the less energy returned to the engines of a D. C. Diesel electric plant.

A point which puzzles the writer is how a propeller, regardless of full speed slip, can be considered to exert a negative torque peak of a value which is a definite percentage of full ahead torque when passing through, for instance, 35% of full ahead R.P.M. with V_a held constant at that value corresponding to full speed. For example, suppose a 10′ × 10′ wheel is used at 25 knots V_a behind two hulls. The first hull requires 6000 S.H.P. which means about 300 R.P.M., 15% slip, an efficiency of 72%, and a torque of around 105,000 foot-pounds, while the second, neglecting cavitation, requires about 388 R.P.M., 35% slip, has 64% efficiency, and 257,000 foot-pounds torque. Now suppose the propeller was brought to rest in each case while maintaining hull speed constant at the full speed. Would not a super intelligent propeller be required to know that in the first case it must exert a peak negative torque of perhaps 90% of 105,000 foot-pounds at 120 R.P.M. and that in the second case while being dragged through the water under the same conditions at the same speed it must exert a peak of 90% of 257,000 foot-pounds at around 155 R.P.M.? It would appear that the peak negative torque should be the same in either case, say 90% in the first and 37% of full ahead in the second. These are rather extreme examples yet the 15% slip example is near peak propeller efficiency while the other is not working above slips sometimes used. For instance, the tank tests of the Coast Guard Cutter *Northland* indicate a slip of nearly 40% at 12.5 knots.

As soon as slip becomes negative the convex side of the propeller instead of the flat side becomes the pressure side. Propellers tested under this condition show lower torque and thrust coefficients than for equal slips driving with the flat face over the

limited range of slips it has been possible to test, which is to be expected since effective pitch is greater than face pitch when the flat face is driving while going ahead and less than face pitch when going astern, but little data applicable to full scale conditions can be found covering the high slips existing over most of the period of stopping.

It might be of interest to point out that with the usual definition of slip or slip ratio as $\frac{\text{Speed of propeller—speed of advance}}{\text{Speed of propeller}}$ the slip becomes 100% when R.P.M. are maintained constant but speed of advance is reduced to zero. Also if speed of advance be made 100% of speed of propeller but with the propeller still turning ahead and the vessel moving astern at a speed equivalent to propeller speed, slip will be 200%. However, if we hold speed of advance constant and reduce propeller R.P.M. so speed of propeller is ½ of speed of advance, the propeller has a negative slip of 100% and this slip increases on further reduction of propeller speed, approaching infinity as propeller speed approaches zero. After the propeller begins turning astern with the ship still going ahead through the water, the slip by the above formula decreases with increasing revolutions as shown in Figure 22.

The apparent slip from R.P.M. and velocity curves is plotted in run 1R. At 20 knots this is around 17% which, with a wake of 3%, gives 21% slip. This propeller, from the propeller model curve, shows zero thrust at around 7% slip and as zero thrust occurs at 40% in run 1R this would indicate a 33% wake. In view of the questionable data the accuracy of this point should not be taken too seriously.

It would appear reasonable to expect that during the period of deceleration apparent resistance would be decreased and that the wake effect would increase because the velocity of the vessel is decreasing in relation to the frictional belt and wake. When the bow passes a given mass of water it is moving faster than is the stern when this mass passes the propeller. The greater this increase of wake the lower the propeller revolutions for zero thrust and the longer the time that propeller torque is assisting the astern steam in stopping the turbines and also the longer the period be-

fore propeller thrust begins to assist hull resistance in retarding the vessel. This change in wake at the propeller would appear to be in addition to any apparent increase in the mass of the vessel to be stopped due to the mass of the boundary layer.

Figure 20 shows the combined curves of R.P.M. and curves of speed and propeller thrust for some of the trials of the *Duane* where the vessel was stopped from 20 knots. Also there is shown a deceleration curve (A) computed by the method given in an article in the February, 1916, issue of the JOURNAL and a curve (B) computed by formula from an article in the August, 1938, issue of the JOURNAL, both articles by Admiral S. M. Robinson, U. S. Navy. The comparison of computed curves with test curves, even if only approximately correct, appears to prove the fallacy of assuming that a constant effective astern power is available or that thrust increases as speed is reduced, thus approaching infinity when speed approaches zero as indicated by the formula of (A). Curve (B) was computed on the assumption that 80% astern torque was instantly available merely to show the type of curve.

A general conclusion drawn from this study is that more can be done to reduce the stopping distance and time of full powered vessels by decreasing the time interval between the astern signal and the time propellers are turning astern (or what is probably of greater importance, the time that a considerable astern torque is applied) than by increasing power as represented by higher astern R.P.M. later in the maneuver.

Hydraulic operated ahead and astern maneuvering gear would appreciably reduce the distance through the water at the higher speeds. With a geared turbine job the maximum practicable torque can be used effectively early in the stopping period where the astern turbine torque is assisting propeller torque to absorb the momentum of gears and rotors while an astern torque of, for instance, 60% of full ahead torque at 60% of full ahead R.P.M. appears adequate for a 20-knot vessel of this type when the ship's forward speed is approaching zero or vessel is going astern.

A form of specification is proposed for geared turbine installations requiring turbines to be brought to rest in a definite time, after signal (say, 30 seconds for this size and type of vessel, from designed full speed of the vessel). In addition, the astern turbine

should develop sufficient power to turn the propeller at a stated number of R.P.M. after steady astern conditions are reached, without exceeding about 100% of the designed full speed ahead steam flow, depending upon type of boiler and fuel burning equipment (reserve steam and heat storage capacity and ability to respond quickly).

A definite time interval would leave the designer free to choose any combination of the factors of speed of maneuvering gear, moment of inertia of turbines and gears, and amount of astern torque of turbine during the first part of the stopping period; while final astern R.P.M. and power would depend upon the propeller and the characteristics desired in the particular type of vessel. For a normal vessel, ability to back at more than 10 or 12 knots would appear to be of questionable value whether the designed full speed ahead be 12 or 30 knots.

If an astern torque-R.P.M. curve determined at one end by the torque required to stop the propeller in 30 seconds and at the other end by an astern R.P.M. corresponding to 12 knots ahead be accepted as a reasonably safe amount of stopping power, then it appears to follow that less astern power than is usually specified is required for normal astern operation but that more torque than is usually provided on high speed geared turbine driven vessels should be available sooner after the astern bell is given. This would appear to indicate more diameter and stages and less nozzle areas or possibly a re-entry type of astern turbine. Of course the disadvantages of a longer turbine rotor and greater ahead rotational losses are points against the more efficient astern unit.

While measurements of torque during the period of stopping between the bell and zero R.P.M. are considered very questionable it should be noted that no readings higher than 75% of full ahead torque were obtained before zero R.P.M. On the slow speed tests torque does exceed 100% of the ahead torque corresponding to the speed from which the backing test began. However, the 30% of full ahead power available on these reduced speed tests corresponds to approximately 100% astern power at 15 knots and to 360% of the ahead power required at 10 knots.

It would appear from a consideration of the many variables involved (such as delay due to maneuvering gear, momentum of

machinery, first a positive then negative torque applied by the propeller, varying exponential powers of the hull resistance curve during stopping, and especially the varying ratios of propeller pitch, and ratios of area to displacement and power of different types of vessels) that the development of a usable rational formula for backing power is impracticable, and that "percentage of astern power" is very indefinite and practically meaningless by itself as a factor in stopping time.

As the average time from bell to break in R.P.M. curve appears to be about eight seconds and a rough simple approximation of the velocity-time curve of the 20-knot runs, when all available steam pressure was used on either one or both nozzles, would be a straight line beginning about eight seconds after the break in revolutions and having a slope given by 101% of full ahead thrust an approximate formula might be derived *for this ship at this speed,* giving time and distance of stopping after the astern bell in terms of effective horsepower, displacement and speed as follows:

Time = velocity in feet ÷ negative acceleration in feet per second + 16 seconds delay.

Negative acceleration in feet per second = 32.16 × force in tons ÷ displacement in tons.

Force in tons = 101% full speed thrust, but full speed thrust in

$$\text{tons} = \frac{\text{E.H.P.} \times 550}{\text{v} \times 2240}$$

when (v) is expressed in feet per second.

Then time of stopping in seconds after bell is reduced to =

$$16 + \frac{.36\Delta V^2}{\text{E.H.P.}}$$

when (V) is expressed in knots and displacement (Δ) in tons.

Distance (in yards after the constant decelerating force is assumed to begin to act) = ½ Vt, therefore, approximate distance in yards after the bell = $9V + \frac{.1\Delta V^3}{\text{E.H.P.}}$.

Applying the above formulas to the turbo-electric drive cutter *Modoc* but not allowing the 16 seconds for delay gives a stopping

time of 107 seconds and a distance of 516 yards. The tests give 500 and 483 yards when going directly from ahead to induction motor astern.

The "9" in the above formula may be considered a constant whose value should depend upon the delay in bringing the decelerating force into action and the 0.1 a constant depending upon both average value and distribution in time of this force. Perhaps by assuming a proper constant representing delay after the bell before the decelerating force becomes effective and a proper value of the average decelerating force such a formula might be made to apply to the other types of drive and other classes of ships. This is merely assuming that the velocity-time curve during deceleration is replaced by straight lines as A-B and B-C with B-C of Figure 20 passing through zero velocity a proper time interval after the astern signal and having a slope (determined by the average force acting and its distribution) such that the area under the straight lines ABCD after the signal is the same as that under the actual velocity-time curve. It scarcely need be pointed out that most such empirical formulas may have constants inserted to give the correct answer in a particular case if the answer is already known, or if experience is depended upon to supply unknown values this experience might lead to as accurate results through a direct guess at the final answer as through a formula. Such values of the constant which represents delay and the constant which represents decelerating force could be found for any vessel such that the formula would give both a correct time and correct distance, though a negative time-of-delay constant might be necessary in case of a very concave velocity-time curve, that is, one showing a very rapid drop in velocity soon after the bell, then dropping at a slower rate as velocity is reduced or with increasing time. Such a curve would be expected from a hull driven at a very high speed length ratio and with small backing power, also from a turbo-electric vessel with low motor inertia if "plugged" from full speed ahead to induction operation astern, since it might be expected that a fair amount of astern torque would be brought to act on the propeller quickly and that the early part of curve would be concave due to a high and decreasing hull and propeller resistance. The velocity-time curves obtained on the *Duane* appear in general to be convex

at the beginning and concave at lower speeds if they may be said to have a general tendency. Slower maneuvering gear and greater machinery momentum should tend to make the beginning of the curve convex by delaying and making the application of the decelerating force from the propeller more gradual.

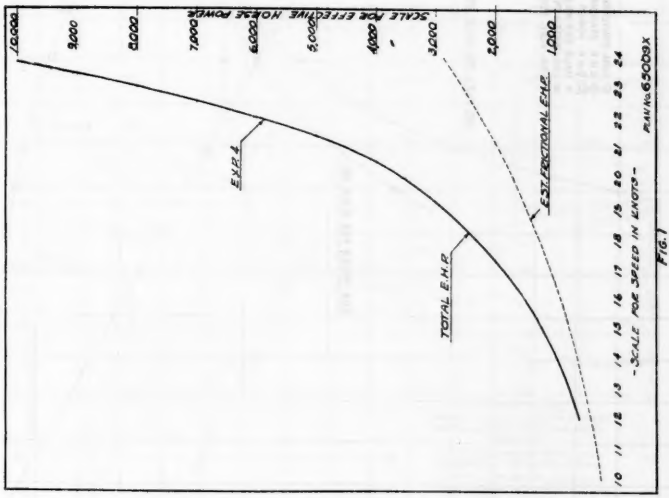
It may be noted on examining the formulas used by Admiral Robinson that the formula of 1916, by assuming a force increasing as velocity is reduced, gives a convex curve while that of 1938 considers force to decrease as velocity decreases and thus gives a concave curve and less distance if the same time is assumed. In a discussion of the paper referred to above by Mr. Walter E. Thau, it was brought out that of 15 vessels all gave distances less than that assumed by a constant decelerating force. If data is correct this would indicate concave velocity-time curves having less area than under a straight line, or more of the shape given by the 1938 type of formula.

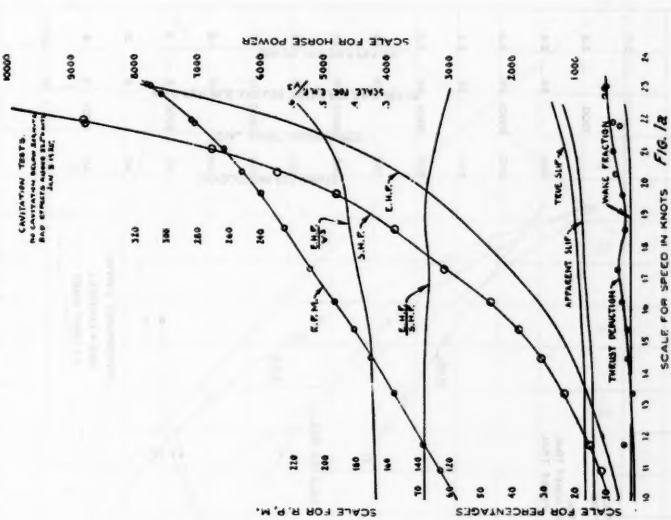
The common reasoning that increased torque at the propeller and increased astern propeller R.P.M. during the early part of stopping will necessarily give a greater decelerating force is not at all apparent to the writer. During normal ahead operation of the propeller the effect is that of a low pressure area in the plane of propeller, stream lines converge on the propeller disk and velocity through the propeller is greater than the speed of advance of the vessel. It would appear that as thrust approaches zero this pressure at the propeller increases, and velocity through the propeller disk approaches the velocity of advance, further reduction in propeller speed or reversal of the propeller would increase pressure ahead of the propeller, stream lines would diverge past the propeller and velocity through the disk would become less than the speed of advance. At some time before the vessel stops flow through the propeller disk undoubtedly reverses and circulation is established from the after side. The slip stream may extend well forward before the vessel is dead in water. No doubt the time when this reversal of flow occurs varies with different ships and could be expected to be influenced by many factors such as speed of advance, submergence, propeller area, and R.P.M. It would be expected to occur almost as soon as the propeller is reversed on a slow speed hull but not at 25 knots speeds of advance. It is con-

ceivable that in a very slow speed hull a circulation from astern is soon established and the angle of attack of the propeller blade during most of the stopping period is low, but that in a high speed hull the vector representing velocity of approach becomes less than the speed of advance but does not reverse at high speeds. Thus the angle of attack becomes about 90 degrees at a low astern propeller R.P.M. Unless the water approaching from the forward side can be given a velocity forward relative to the propeller it is difficult to see how a greater braking resistance can be obtained from the propellers than from bringing the velocity through the disk to zero until a circulation from the after side can be established since thrust must be proportional to the fore and aft component of change in momentum of the water passing the propeller. However, it can readily be seen that a greater torque may be absorbed under this condition by turning the propeller faster and giving a greater tangental and radial acceleration to water entering, perhaps, from both sides.

In the *Duane* tests the average total decelerating force acting is only of the order of full speed thrust. Locking the propellers should give about twice this force at the high speed end of the curve according to the paper by Admiral Robinson. Some model tests have given the drag of a three-bladed propeller having a pitch ratio of .833 and projected area ratio of .61 as $1.27\ d^2\ V^2$, where drag is in pounds, diameter (d) in feet,, and velocity (v) in knots. This would give a somewhat greater decelerating force but it would appear reasonable to assume that the greater pitch ratio and less projected area of the *Duane* propellers would cause less drag than the one on which this formula is based.

Accurate full scale tests with high speed hulls and continuously recorded data giving thrust, torque, R.P.M., hull speed, and distance, all against time, together with a study of actual flow through the propeller by stroboscopic high speed moving pictures, are required before accurate knowledge will be developed regarding the transient conditions which exist when stopping vessels.


SCALE FOR EFFECTIVE HORSE POWER
E.H.P.
TOTAL E.H.P.
EST. FRICTIONAL E.H.P.
SCALE FOR SPEED IN KNOTS
FIG. 1


SCALE FOR HORSE POWER
SCALE FOR R.P.M.
SCALE FOR PERCENTAGES
E.H.P.
S.H.P.
E.H.P./S.H.P.
E.R.M.
TRUE SLIP
APPARENT SLIP
WAKE FRACTION
THRUST DEDUCTION
SCALE FOR SPEED IN KNOTS
FIG. 12

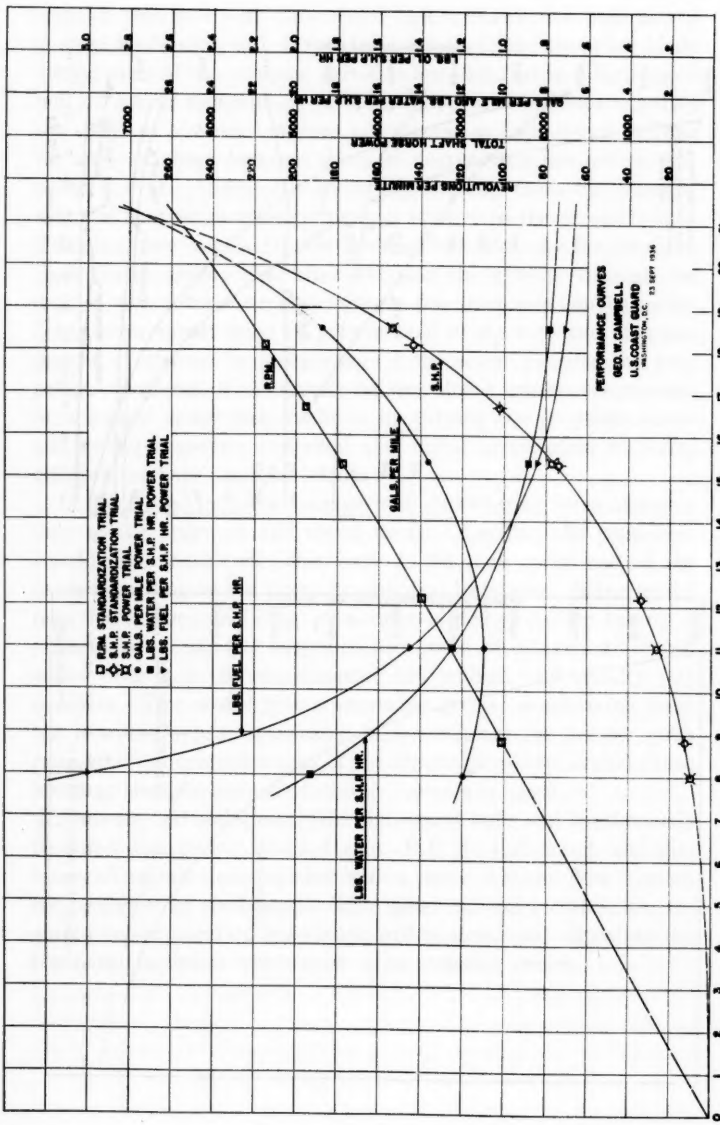

R.P.M. STANDARDIZATION TRIAL
S.H.P. STANDARDIZATION TRIAL
S.H.P. POWER TRIAL
GALS. PER MILE POWER TRIAL
LBS. WATER PER S.H.P. HR. POWER TRIAL
LBS. FUEL PER S.H.P. HR. POWER TRIAL
LBS. FUEL PER S.H.P. HR.
LBS. WATER PER S.H.P. HR.
R.P.M.
S.H.P.
GALS. PER MILE
REVOLUTIONS PER MINUTE
TOTAL SHAFT HORSE POWER
GALS. PER MILE AND LBS. WATER PER S.H.P. PER HR.
LBS. OIL PER S.H.P. PER HR.
SPEED IN KNOTS
PERFORMANCE CURVES
GEO. W. CAMPBELL
U.S. COAST GUARD
WASHINGTON, D.C.
23 SEPT 1936

FIG. 16

SPEED IN KNOTS

FIG. 16

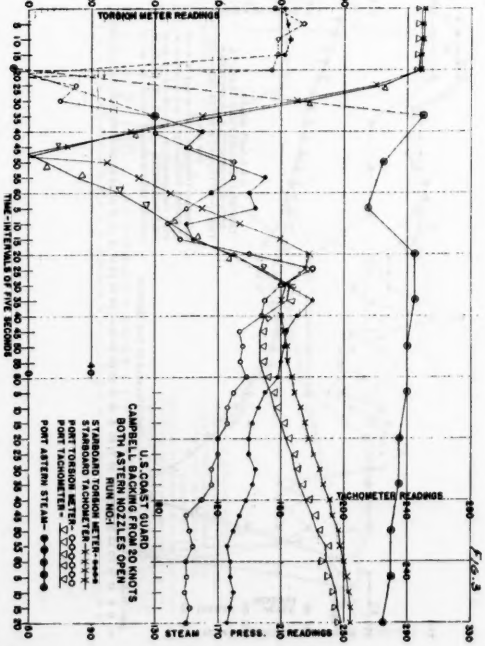


FIG. 3

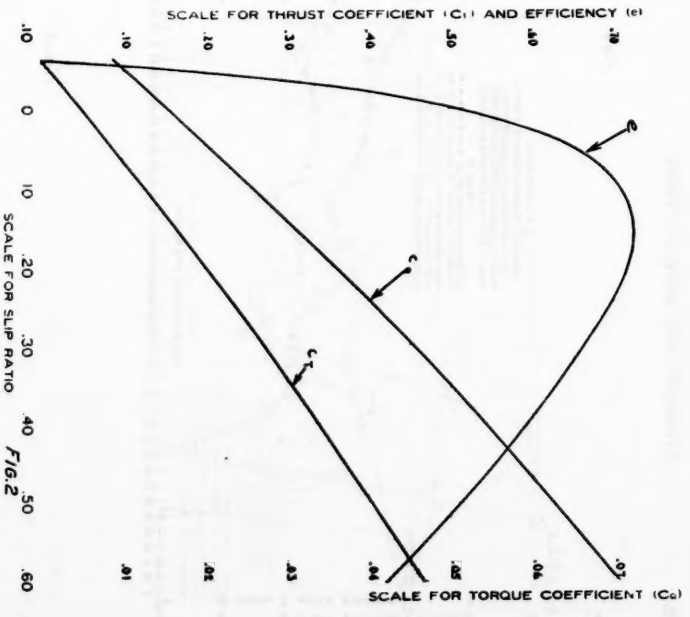


FIG. 2

FIG. 4

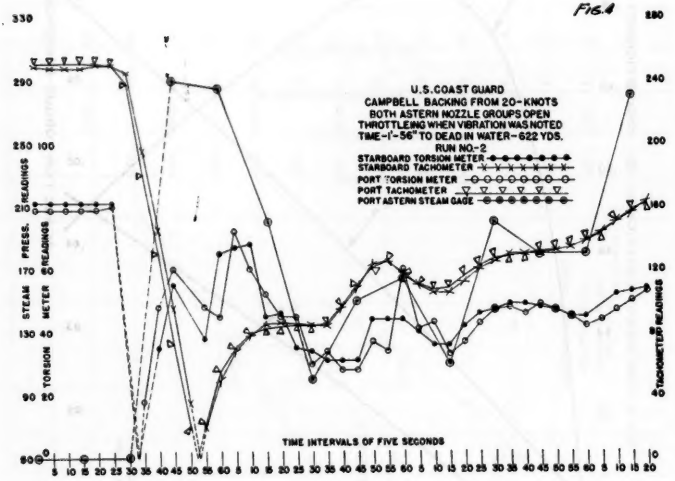

U.S. COAST GUARD
CAMPBELL BACKING FROM 20-KNOTS
BOTH ASTERN NOZZLE GROUPS OPEN
THROTTLEING WHEN VIBRATION WAS NOTED
TIME-1'-56" TO DEAD IN WATER-622 YDS.
RUN NO-2
STARBOARD TORSION METER
STARBOARD TACHOMETER
PORT TORSION METER
PORT TACHOMETER
PORT ASTERN STEAM GAGE
STEAM PRESS. READINGS
TORSION METER READINGS
TACHOMETER READINGS
TIME INTERVALS OF FIVE SECONDS

FIG. 5

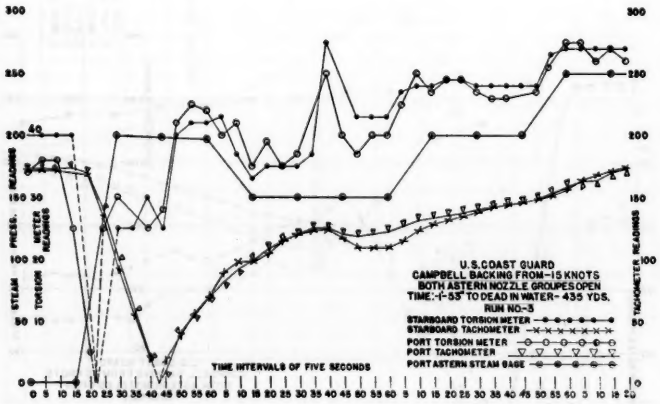

U.S. COAST GUARD
CAMPBELL BACKING FROM-15 KNOTS
BOTH ASTERN NOZZLE GROUPES OPEN
TIME-1'-53" TO DEAD IN WATER-435 YDS.
RUN NO-3
STARBOARD TORSION METER
STARBOARD TACHOMETER
PORT TORSION METER
PORT TACHOMETER
PORT ASTERN STEAM GAGE
STEAM PRESS. READINGS
TORSION METER READINGS
TACHOMETER READINGS
TIME INTERVALS OF FIVE SECONDS

FIG. 6

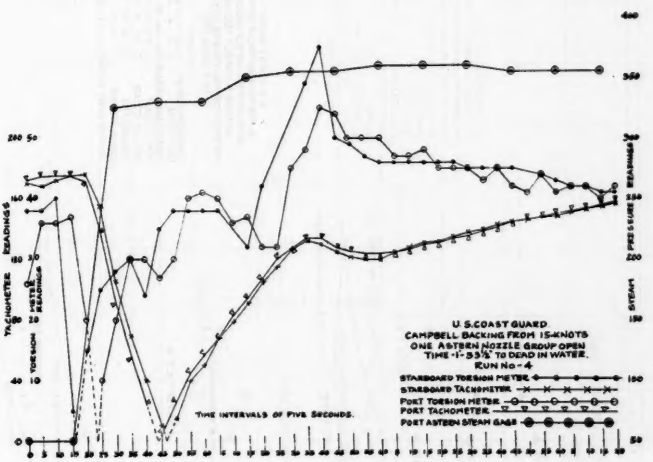
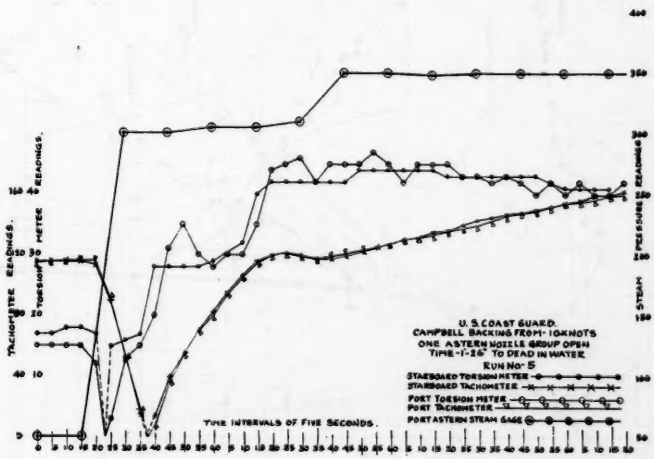

TACHOMETER READINGS
TORSION METER READINGS
STEAM PRESSURE READINGS
U.S. COAST GUARD
CAMPBELL BACKING FROM 15-KNOTS
ONE ASTERN NOZZLE GROUP OPEN
TIME -1-33½" TO DEAD IN WATER.
RUN No - 4.
STARBOARD TORSION METER
STARBOARD TACHOMETER
PORT TORSION METER
PORT TACHOMETER
PORT ASTERN STEAM GAGE
TIME INTERVALS OF FIVE SECONDS.

FIG. 7


TACHOMETER READINGS.
TORSION METER READINGS.
STEAM PRESSURE READINGS.
U. S. COAST GUARD.
CAMPBELL BACKING FROM 10 KNOTS
ONE ASTERN NOZZLE GROUP OPEN
TIME -1-26" TO DEAD IN WATER.
RUN No 5
STARBOARD TORSION METER
STARBOARD TACHOMETER
PORT TORSION METER
PORT TACHOMETER
PORT ASTERN STEAM GAGE
TIME INTERVALS OF FIVE SECONDS.

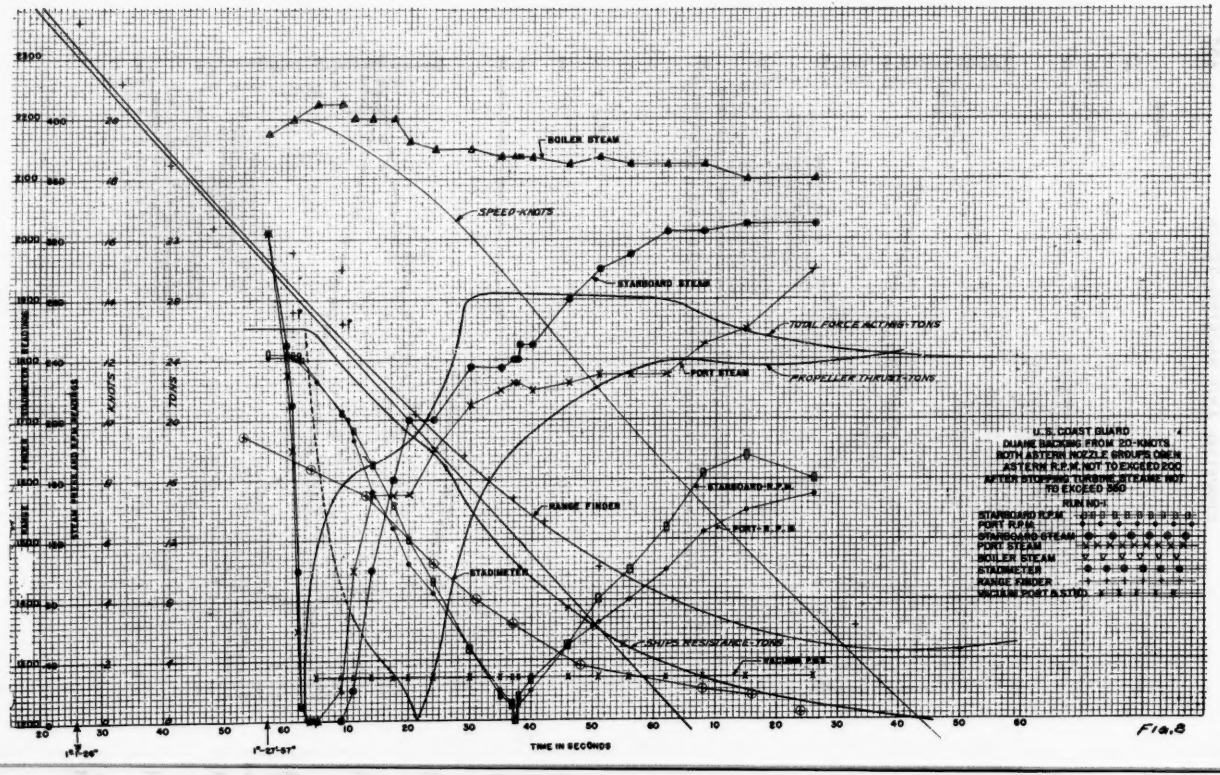

BOILER STEAM
SPEED-KNOTS
STARBOARD STEAM
TOTAL FORCE ACTING-TONS
PORT STEAM
PROPELLER THRUSTS-TONS
STARBOARD R.P.M.
PORT R.P.M.
RANGE FINDER
STADIMETER
HULL RESISTANCE-TONS
VACUUM P.S.I.
TIME IN SECONDS
U.S. COAST GUARD
DUANE BACKING FROM 20-KNOTS
BOTH ASTERN NOZZLE GROUPS OPEN
ASTERN R.P.M. NOT TO EXCEED 200
AFTER STOPPING TURBINE STEAM NOT
TO EXCEED 350
RUN NO.1
STARBOARD R.P.M.
PORT R.P.M.
STARBOARD STEAM
PORT STEAM
BOILER STEAM
STADIMETER
RANGE FINDER
VACUUM PORT & STBD

Fig. 8

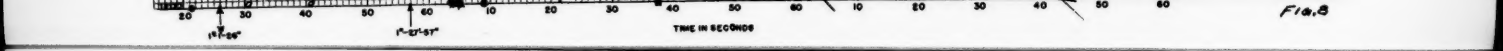

TIME IN SECONDS

Fig.8

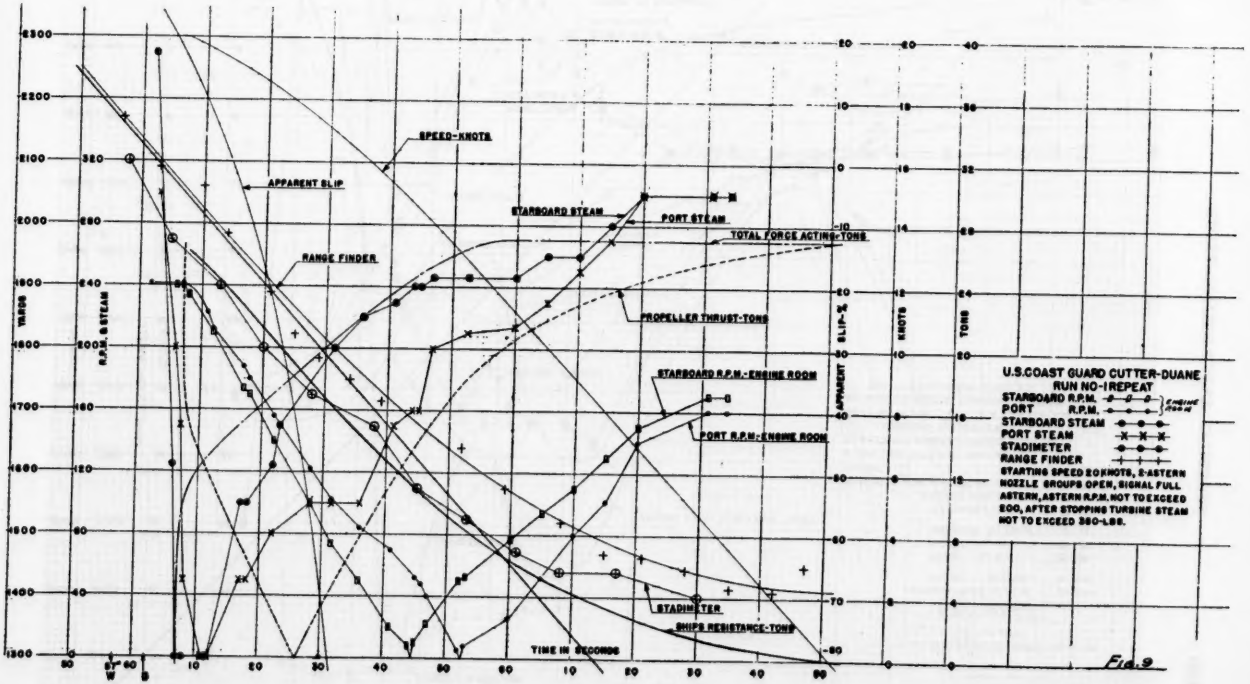
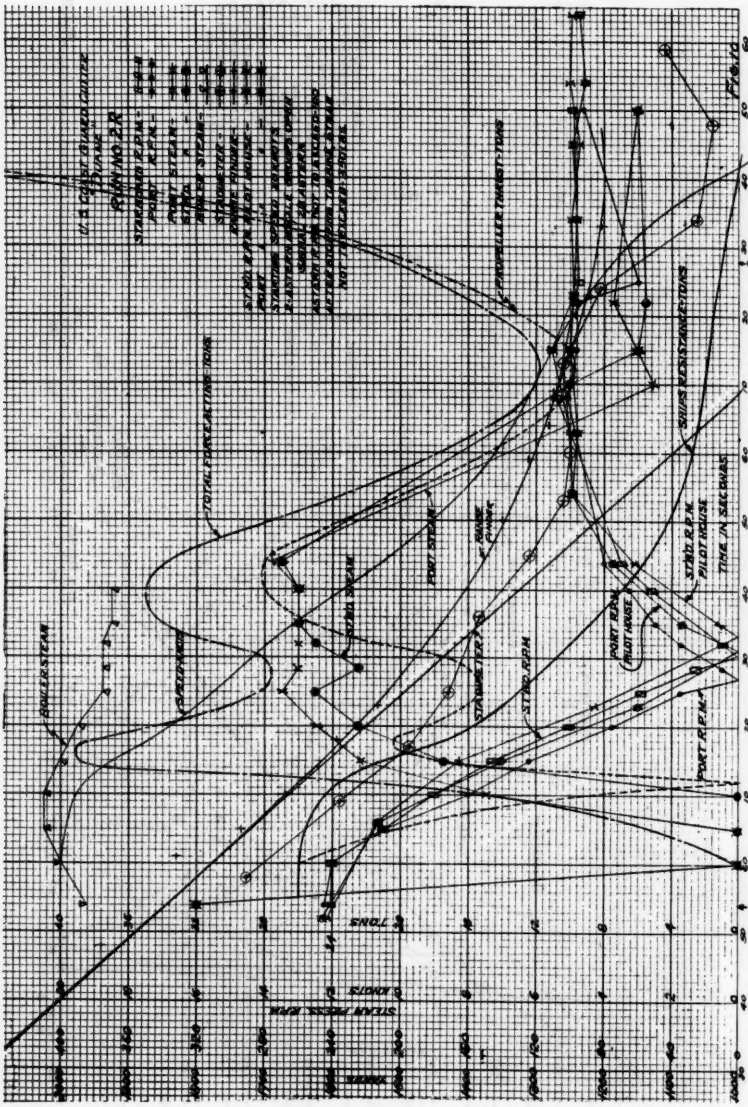

SPEED-KNOTS
APPARENT SLIP
RANGE FINDER
STARBOARD STEAM
PORT STEAM
TOTAL FORCE ACTING-TONS
PROPELLER THRUST-TONS
STARBOARD R.P.M.-ENGINE ROOM
PORT R.P.M.-ENGINE ROOM
STADIMETER
SHIPS RESISTANCE-TONS
TIME IN SECONDS
R.P.M. & STEAM
APPARENT SLIP-%
KNOTS
TONS
U.S.COAST GUARD CUTTER-DUANE
RUN NO-1 REPEAT
STARBOARD R.P.M.
PORT R.P.M.
ENGINE ROOM
STARBOARD STEAM
PORT STEAM
STADIMETER
RANGE FINDER
STARTING SPEED 20 KNOTS, 2-ASTERN NOZZLE GROUPS OPEN, SIGNAL FULL ASTERN, ASTERN R.P.M. NOT TO EXCEED 200, AFTER STOPPING TURBINE STEAM NOT TO EXCEED 350-LBS.

Fig.9


TOTAL FORCE ACTING
STARBOARD
PORT
STEAM
STEAM
STEAM

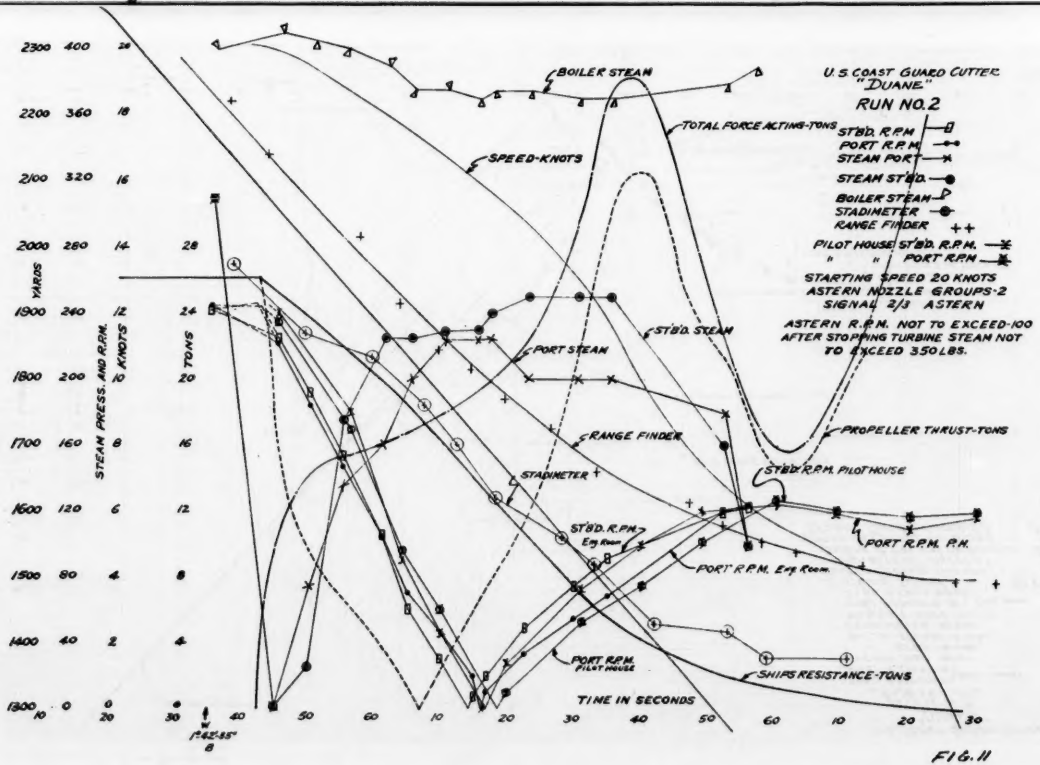
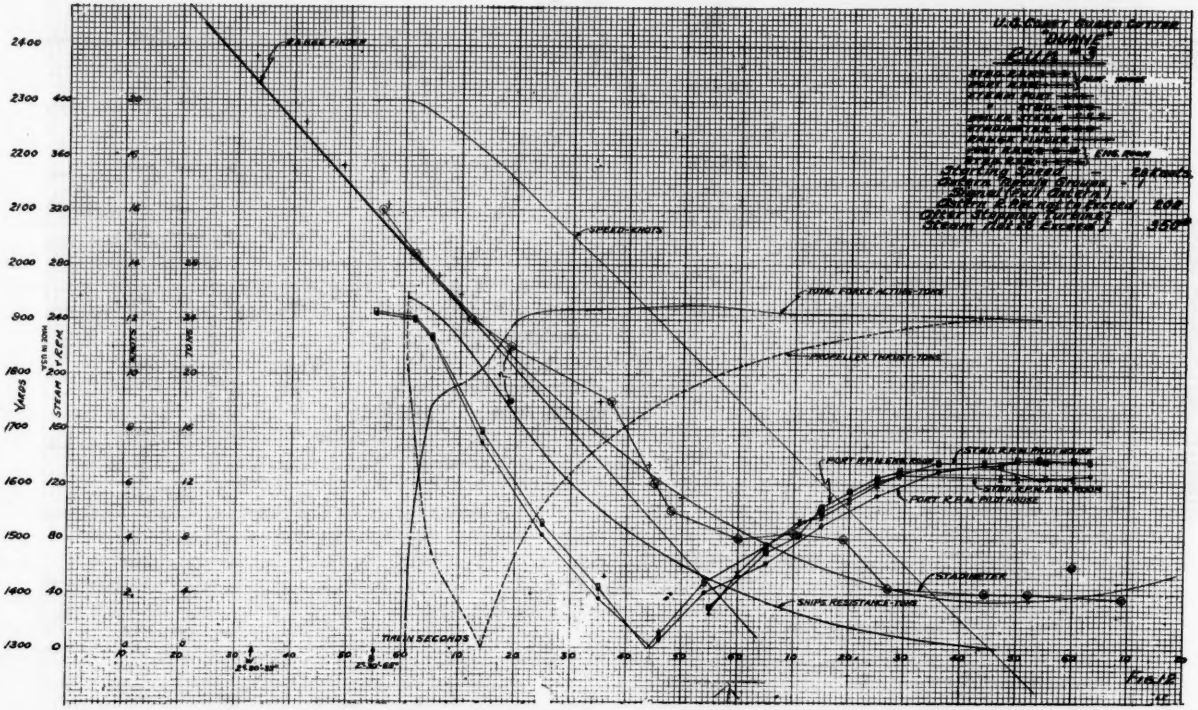
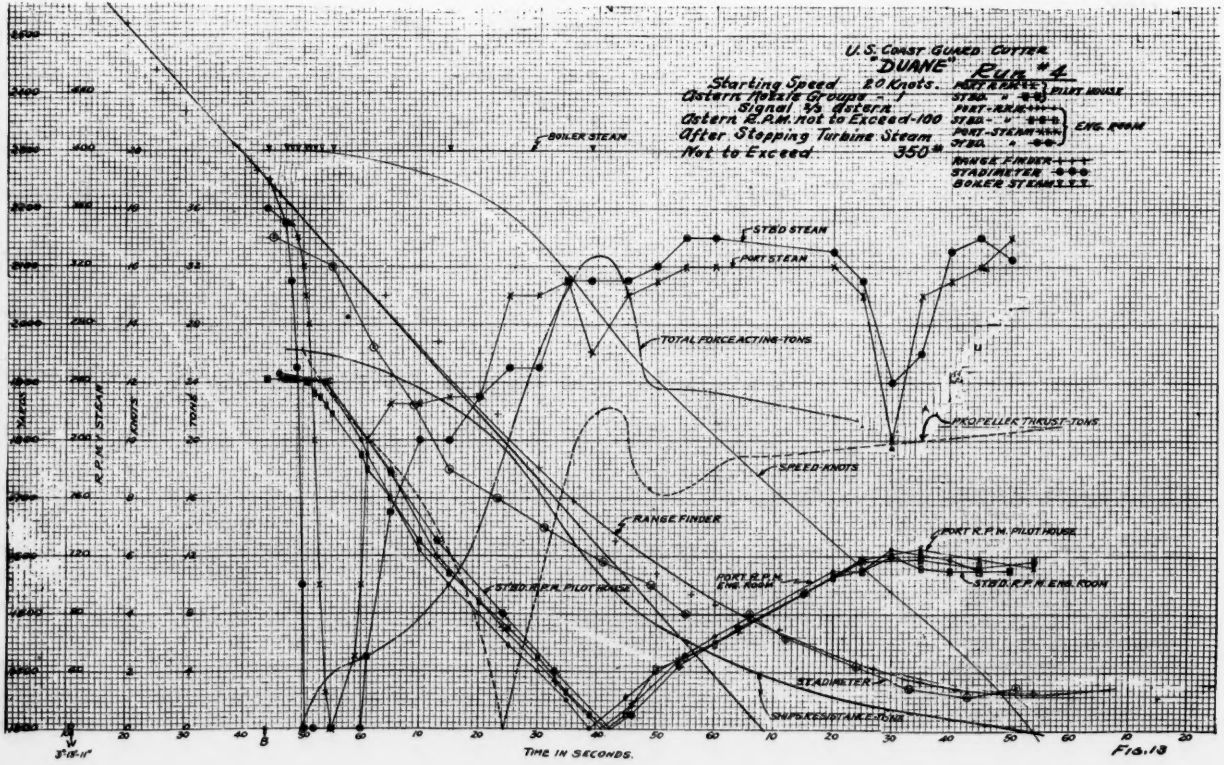

U. S. COAST GUARD CUTTER "DUANE."
RUN NO. 2
STBD. R.P.M.
PORT R.P.M.
STEAM PORT
STEAM STBD.
BOILER STEAM
STADIMETER
RANGE FINDER
PILOT HOUSE STBD. R.P.M.
" " PORT R.P.M.
STARTING SPEED 20 KNOTS
ASTERN NOZZLE GROUPS-2
SIGNAL 2/3 ASTERN
ASTERN R.P.M. NOT TO EXCEED-100
AFTER STOPPING TURBINE STEAM NOT TO EXCEED 350 LBS.
BOILER STEAM
TOTAL FORCE ACTING-TONS
SPEED-KNOTS
STBD. STEAM
PORT STEAM
RANGE FINDER
STADIMETER
PROPELLER THRUST-TONS
STBD. R.P.M. PILOT HOUSE
STBD. R.P.M. Eng Room
PORT R.P.M. P.H.
PORT R.P.M. Eng Room
PORT R.P.M. PILOT HOUSE
SHIPS RESISTANCE-TONS
TIME IN SECONDS
YARDS
STEAM PRESS. AND R.P.M.
KNOTS
TONS
2300 400 20
2200 360 18
2100 320 16
2000 280 14 28
1900 240 12 24
1800 200 10 20
1700 160 8 16
1600 120 6 12
1500 80 4 8
1400 40 2 4
1300 0 0 0

FIG. 11


U.S. Coast Guard Academy
Dahlgren
GULF
Starboard Screw
Port Screw
Rudder
Starting Speed
Speed (Full Power)
Speed (Full Power)
Rudder Not to Exceed 20°
Speed Stopping Turning
Rudder Not to Exceed 35°
R.P.M. FINDER
SPEED-KNOTS
TOTAL FORCE ACTIVE-TONS
PROPELLER THRUST-TONS
STBD. R.P.M. PILOT HOUSE
PORT R.P.M. ENG. ROOM
STBD. R.P.M. ENG. ROOM
PORT R.P.M. PILOT HOUSE
STEAM PRESS.
STEAM TEMP.
KNOTS
TONS
YARDS
TIME IN SECONDS
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
400
360
320
280
240
200
160
120
80
40
0
36
32
28
24
20
16
12
8
4
0
FIG. 12


U.S. Const. Guard. Cutter.
"DUANE" Run. #4
Starting Speed 20 Knots.
Astern Notch Gauge
Signal Vs Astern
Astern R.P.M. not to Exceed-100
After Stopping Turbine Steam
Not to Exceed 350#
PORT R.P.M. PILOT HOUSE
STBD. " "
PORT-R.P.M. ENG. ROOM
STBD. " "
PORT-STEAM
STBD. "
RANGE FINDER
STADIMETER
BOILER STEAM
BOILER STEAM
STBD STEAM
PORT STEAM
TOTAL FORCE ACTING-TONS.
PROPELLER THRUST-TONS.
SPEED KNOTS
RANGE FINDER
PORT R.P.M. PILOT HOUSE
STBD. R.P.M. ENG. ROOM
PORT R.P.M. ENG. ROOM
STBD. R.P.M. PILOT HOUSE
STADIMETER
SHIPS RESISTANCE-TONS
TIME IN SECONDS.
Fig. 13

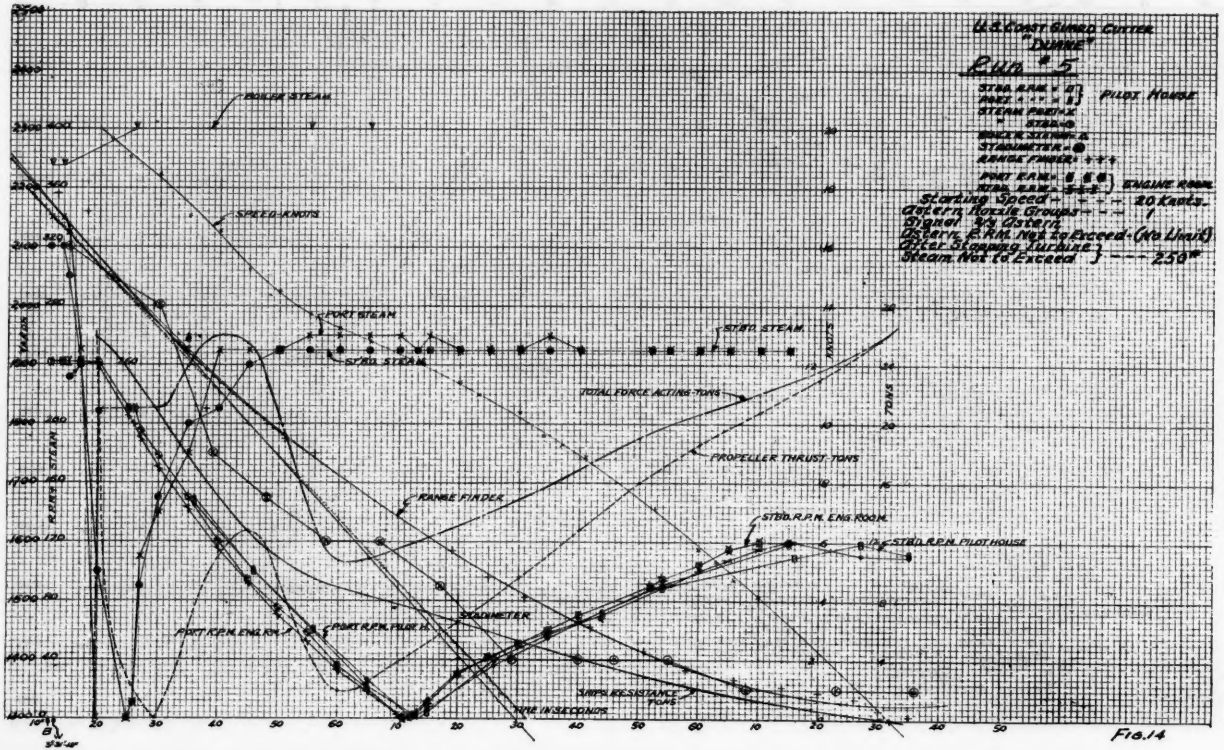
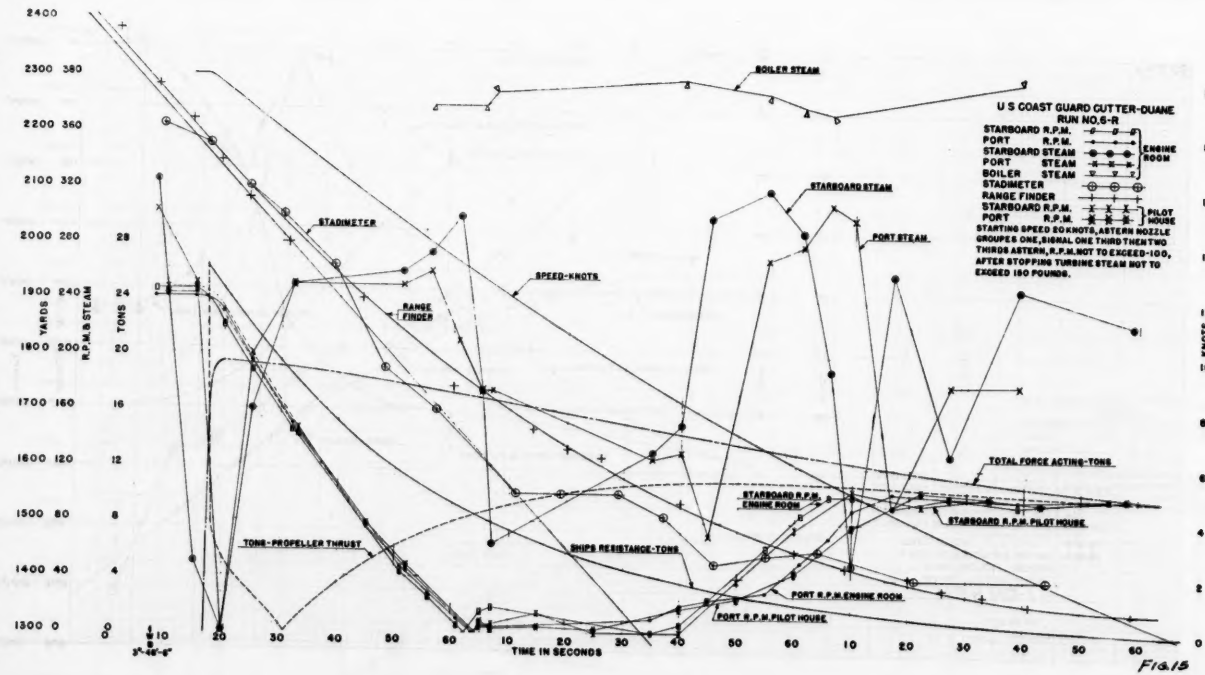
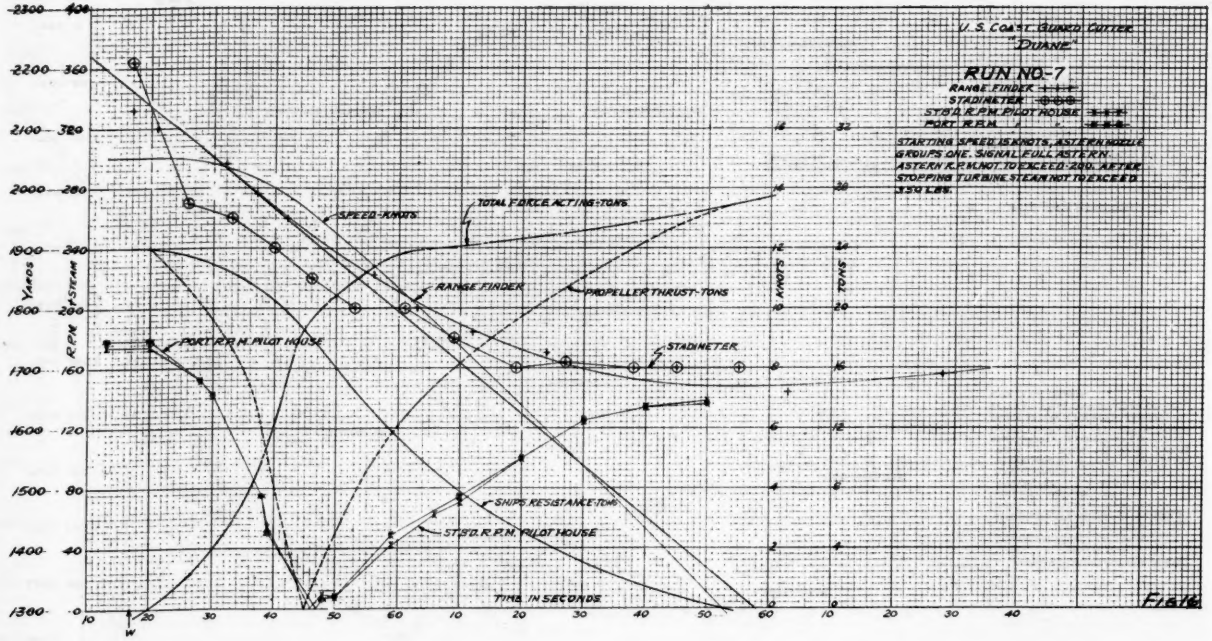

U.S. Coast Armed Cutter "Dexter"
Run # 5
Pilot House
Engine Room
Starting Speed - - - - - - 20 knots.
Astern Nozzle Groups - - - 1
Signal 3 Astern
Astern R.P.M. Not to Exceed (No Limit)
After Stopping Turbine Steam Not to Exceed - - - 250#
BOILER STEAM
SPEED-KNOTS
PORT STEAM
STBD. STEAM
TOTAL FORCE ACTING-TONS
PROPELLER THRUST-TONS
RANNIE FINDER
STBD. R.P.M. ENG. ROOM
STBD. R.P.M. PILOT HOUSE
STARBOARD R.P.M. ENG. RM.
PORT R.P.M. PILOT H.
STARBOARD
PORT R.P.M. ENG. RM.
SKIN RESISTANCE PLUS
TIME IN SECONDS

Fig. 14

FIG.14


U S COAST GUARD CUTTER-DUANE
RUN NO.6-R
STARBOARD R.P.M.
PORT R.P.M.
STARBOARD STEAM
PORT STEAM
BOILER STEAM
ENGINE ROOM
STADIMETER
RANGE FINDER
STARBOARD R.P.M.
PORT R.P.M.
PILOT HOUSE
STARTING SPEED 20 KNOTS, ASTERN NOZZLE GROUPS ONE, SIGNAL ONE THIRD THEN TWO THIRDS ASTERN, R.P.M. NOT TO EXCEED-100, AFTER STOPPING TURBINE STEAM NOT TO EXCEED 150 POUNDS.
BOILER STEAM
STARBOARD STEAM
PORT STEAM
STADIMETER
SPEED-KNOTS
RANGE FINDER
TOTAL FORCE ACTING-TONS
STARBOARD R.P.M. ENGINE ROOM
STARBOARD R.P.M. PILOT HOUSE
TONS-PROPELLER THRUST
SHIPS RESISTANCE-TONS
PORT R.P.M. ENGINE ROOM
PORT R.P.M. PILOT HOUSE
YARDS
R.P.M. & STEAM
TONS
KNOTS
TIME IN SECONDS
FIG.15


U. S. COAST GUARD CUTTER
"DUANE"
RUN NO-7
RANGE FINDER
STADIMETER
ST'D R.P.M. PILOT HOUSE
PORT R.P.M.
STARTING SPEED IS KNOTS, ASTERN NOZZLE GROUPS ONE. SIGNAL FULL ASTERN. ASTERN R.P.M. NOT TO EXCEED 200. AFTER STOPPING TURBINE, STEAM NOT TO EXCEED 150 LBS.
YARDS
R.P.M.
P. STEAM
SPEED-KNOTS
TOTAL FORCE ACTING-TONS
RANGE FINDER
PROPELLER THRUST-TONS
PORT R.P.M. PILOT HOUSE
STADIMETER
SHIPS RESISTANCE-TONS
ST'D R.P.M. PILOT HOUSE
TIME IN SECONDS
KNOTS
TONS
FIG 16

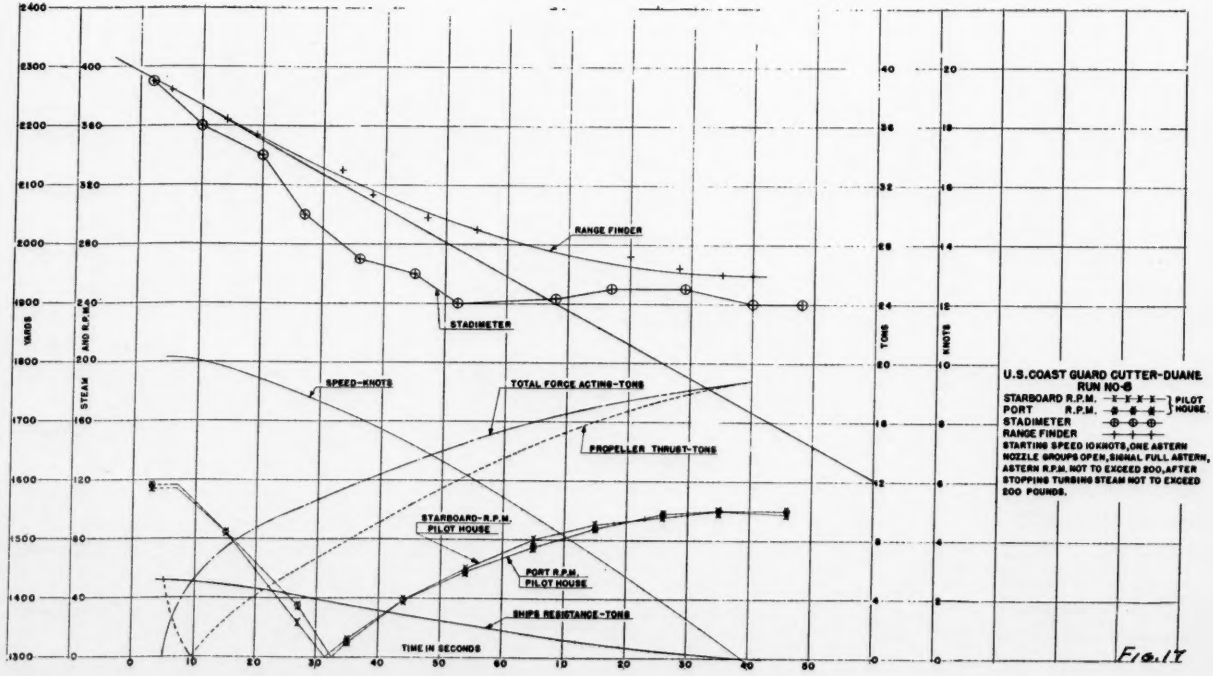

YARDS
STEAM AND R.P.M.
TONS
KNOTS
RANGE FINDER
STADIMETER
SPEED-KNOTS
TOTAL FORCE ACTING-TONS
PROPELLER THRUST-TONS
STARBOARD-R.P.M. PILOT HOUSE
PORT R.P.M. PILOT HOUSE
SHIPS RESISTANCE-TONS
TIME IN SECONDS
U.S.COAST GUARD CUTTER-DUANE
RUN NO-6
STARBOARD R.P.M. } PILOT
PORT R.P.M. } HOUSE
STADIMETER
RANGE FINDER
STARTING SPEED 10 KNOTS, ONE ASTERN NOZZLE GROUPS OPEN, SIGNAL FULL ASTERN, ASTERN R.P.M. NOT TO EXCEED 200, AFTER STOPPING TURBINE STEAM NOT TO EXCEED 200 POUNDS.

Fig. 17

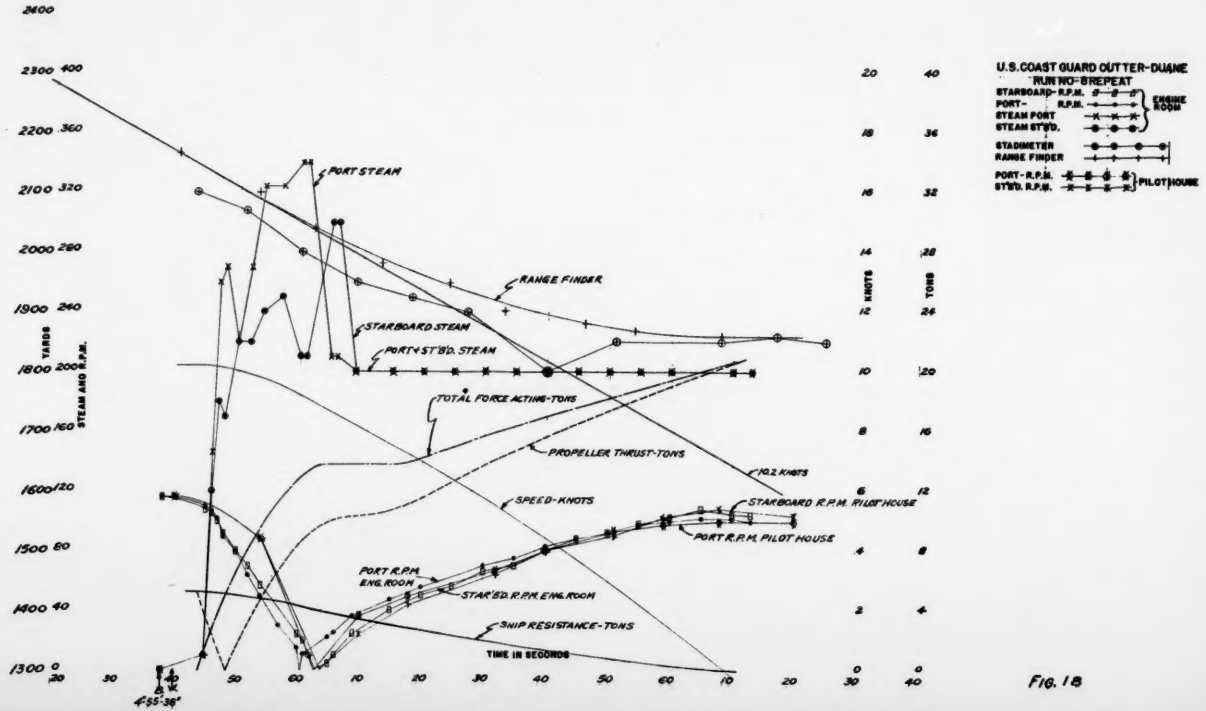
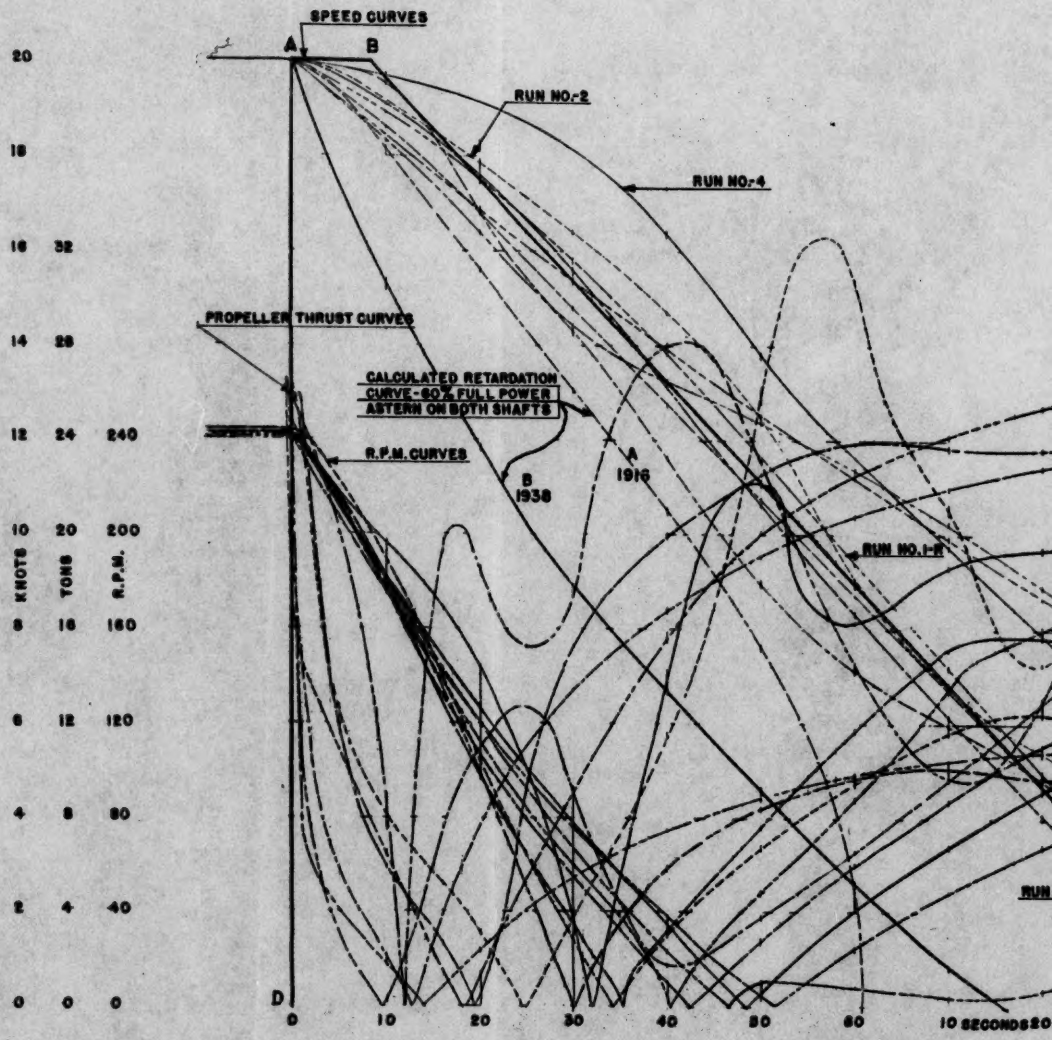

U.S. COAST GUARD CUTTER-DUANE
RUN NO-8 REPEAT
STARBOARD- R.P.M.
PORT- R.P.M.
STEAM PORT
STEAM ST'BD.
ENGINE ROOM
STADIMETER
RANGE FINDER
PORT- R.P.M.
ST'BD. R.P.M.
PILOT HOUSE
PORT STEAM
RANGE FINDER
STARBOARD STEAM
PORT & ST'BD. STEAM
TOTAL FORCE ACTING-TONS
PROPELLER THRUST-TONS
10.2 KNOTS
SPEED-KNOTS
STARBOARD R.P.M. PILOT HOUSE
PORT R.P.M. PILOT HOUSE
PORT R.P.M. ENG. ROOM
STAR'BD. R.P.M. ENG. ROOM
SHIP RESISTANCE-TONS
TIME IN SECONDS
STEAM AND R.P.M.
YARDS
KNOTS
TONS
4°55'-38"

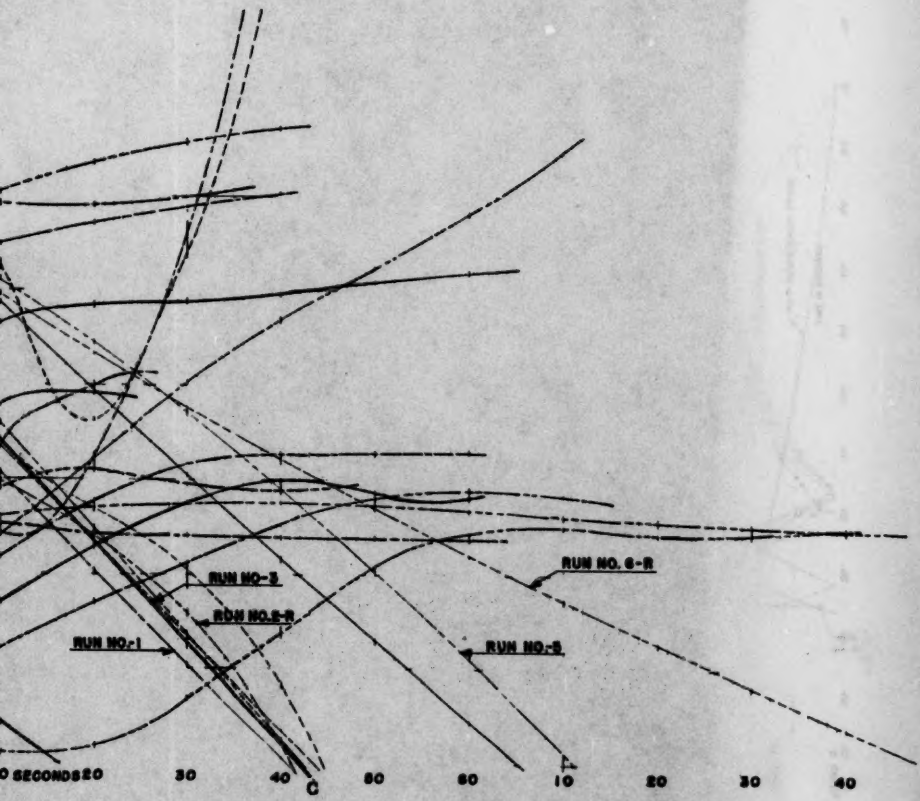
FIG. 18

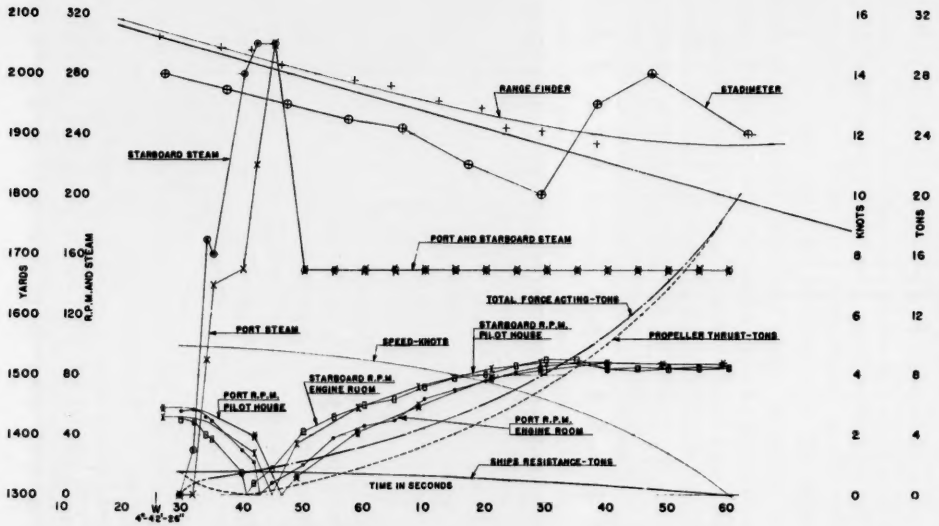

SPEED CURVES
A
B
RUN NO.-2
RUN NO.-4
PROPELLER THRUST CURVES
CALCULATED RETARDATION CURVE - 80% FULL POWER ASTERN ON BOTH SHAFTS
R.P.M. CURVES
A 1916
B 1938
RUN NO.1-R
RUN
D
20
18
16 32
14 28
12 24 240
10 20 200
8 16 160
6 12 120
4 8 80
2 4 40
0 0 0
KNOTS
TONS
R.P.M.
0
10
20
30
40
50
60
10 SECONDS
20

U S COAST GUARD CUTTER-DUANE
SPEED, PROPELLER THRUST & R.P.M. CURVES
FOR 20 KNOT RUNS

SYMBOL TO CURVES	RUN NO.	TIME FROM BREAK IN R.P.M. TO ZERO R.P.M. SECONDS	TIME TO STOP AFTER R.P.M. BEGINS TO DECREASE	DISTANCE YARDS	APPROX. SPEED	R.P.M.	NOZZLE GROUPS IN USE
	1	35	101	600	20	244	2
	1-R	41	104	650	20	240	2
	2	35	105	640	20	242	2
	2-R	30	102	580	20	240	2
	3	44	104	640	20	244	1
	4	50	112	800	20	240	1
	5	52	132	760	20	240	1
	6-R	48	161	840	20	244	1

Fig. 20



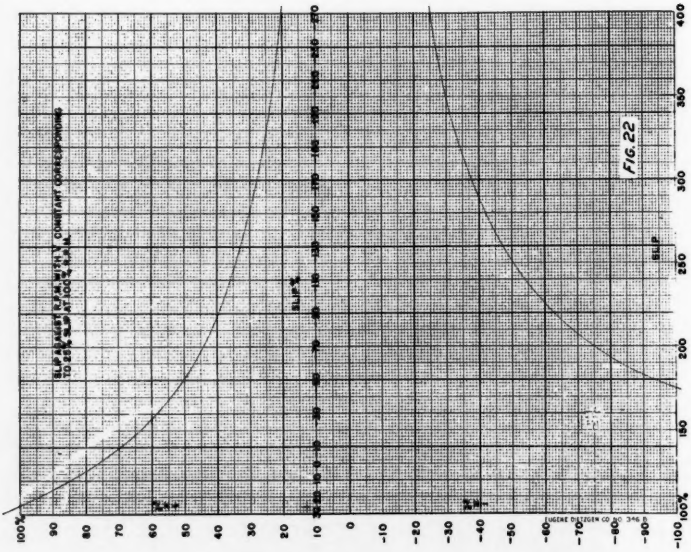


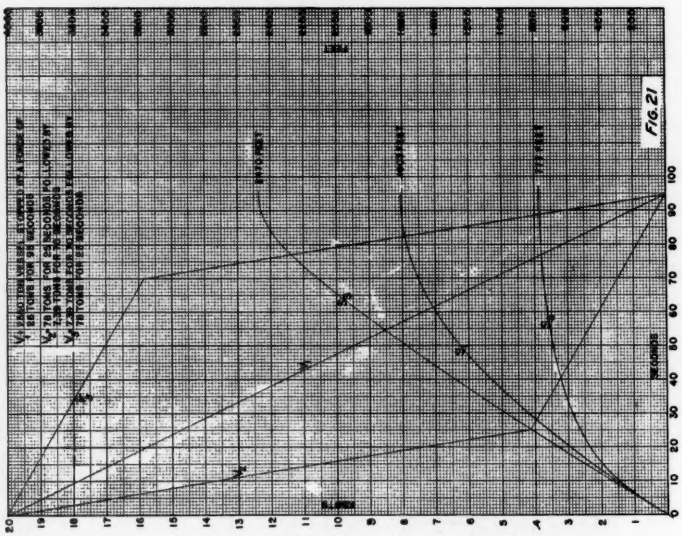
U.S.COAST GUARD CUTTER-DUANE
RUN NO NINE

STARBOARD R.P.M. } ENGINE ROOM
PORT R.P.M. }
STARBOARD STEAM
PORT STEAM
RANGE FINDER
STADIMETER
STARBOARD R.P.M. } PILOT HOUSE
PORT R.P.M. }

STARTING SPEED FIVE KNOTS, ONE ASTERN NOZZLE GROUP OPEN, SIGNAL FULL ASTERN, AFTER STOPPING TURBINE STEAM NOT TO EXCEED 150 LBS., ASTERN R.P.M. NOT TO EXCEED 200.

FIG 19


SLIP
EUGENE DIETZGEN CO. NO. 346
FIG. 22


SECONDS
FIG. 21

ENGINEERING MONEY.

By Lieutenant Commander J. E. Hamilton, U. S. Navy, Member.*

The scope of an engineer's work is determined in part by the extent to which his activities are financed and by the methods of financing. The study which has been made by the author seems to indicate that a definite advantage would be gained by better integration of the laws and regulations which cover the responsibility for and the financing of machinery in naval ships. He offers three methods by which this may be accomplished and explains the advantages and disadvantages of each method.

In 1862, in the midst of war, Congress severed the umbilical cord which for twenty years had carried engineering funds from the Chief Constructor to the Engineer-in-Chief. The Bureau of Steam Engineering was established as an independent organization. Simultaneously an operation removed certain functions from the Chief Constructor and turned them over to a newcomer, the Chief of the Bureau of Equipment. The act of separation was followed by an act dividing the appropriation which had been made for defraying the cost of the Bureau of Construction. The split was three ways, to the renamed parent the Bureau of Construction and Repair, and to the two new Bureaus—Steam Engineering, and Equipment. In one sense, the existence of a major war probably simplified the operation. There was sufficient money for all purposes and no cause for disagreement on the amount of settlement to be made on the youngsters.

As the Bureaus were originally established, Congress gave them names and nothing more. The assignment of specific duties was left to the Secretary of the Navy. This he did by letters to the three Chiefs of Bureau, which directed the Bureau of Construc-

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tion and Repair to turn over to the Bureau of Steam Engineering "all matters pertaining to steam machinery and engineering stores with materials, labor, and bills of expenses connected therewith, hitherto under the Bureau of Construction;" and to the Bureau of Equipment "all matters pertaining to fuel, hemp and rigging and sails, anchors and cables, furniture, cooking utensils, stores of master, boatswains, and sailmakers, together with towage, pilotage and recruiting, and transportation of men, with the materials and labor and bills of expenses connected therewith."

There are jobs which can be done without money. Running a material bureau of the Navy Department is not one of them. Each of the responsibilities of the Engineer-in-Chief required funds for carrying it out. Since the original source of the description of his specific responsibilities was the Secretary of the Navy, it was natural and correct that the same source should provide the money.

Congress appropriated money *to the Secretary of the Navy* for various specific purposes as follows for the fiscal year 1864; which was in general in conformity with the past three years and with the next five:

(*a*) "For the construction and repair of vessels of the Navy."

(*b*) "For the purchase and building of additional steamers, repairs of same, charter of vessels, extra labor and material, and repair of vessels on foreign stations."

(*c*) "For two armor-plated sea steamers of iron of the first class."

(*d*) "For the equipment of vessels in the Navy, namely: for the purchase of various articles of equipment."

(*e*) "For construction and repair of machinery of vessels in commission."

It is apparent that the last cited item approximates the duties of the Bureau of Steam Engineering as described above. Even though money was not appropriated under the heading of the Bureau of Steam Engineering, study of the files of the period indicates that that Bureau had full and complete control of the appropriation. It is further certain that the Bureau of Steam Engineering had complete control of the purchase or manufacture of engines and boilers for the additional vessels appropriated for under the second and third items cited above.

Other funds for the Bureau of Steam Engineering were provided during this period in the Navy Appropriation Bill under the heading of Bureau of Steam Engineering. These were for contingent expenses, namely: transportation of materials, printing, stationery, advertising, books, drawings, models, postage, and incidental expenses. Also in the appropriation for the Legislative, Executive, and Judicial expenses of the government, funds were appropriated under the Bureau of Steam Engineering under the Navy Department for payment of salaries in the Bureau including that of the Engineer-in-Chief.

For the fiscal year 1868 provision was added under each of the bureaus for pay of superintendents and civil establishment in the Navy Yards.

On 1 July 1867, a Navy Department circular detailed the duties of the various bureaus; those of the Bureau of Steam Engineering were "all that relates to the design, building, fitting out, repairing, and engining of the steam machinery used in naval vessels." In this circular each of the bureaus had the duty to "make all contracts and superintend all the work done under it," and "estimate for and pay from their own funds the cost necessary to carry out those duties as above defined."

The duties of the bureaus were revised and reissued by a circular in 1869. Those of the Bureau of Steam Engineering were left exactly as given above. At the same time in the Appropriation Act for the fiscal year 1870 the duties of the bureaus were prescribed by law for the first time. The method of this prescription is of interest because it has become so vitally important to the bureaus. No legal change has ever been made in the duties of the bureaus, that is, as prescribed by the act establishing the bureaus in 1862, their duties shall be as designated by the Secretary of the Navy. Hence, under the basic law the Secretary is free to transfer cognizance from one bureau to another as he sees fit. However, in the Appropriation Bill mentioned, under the head of each bureau was specifically described the purposes for which money was appropriated to that bureau. For the Bureau of Steam Engineering, these duties were described as follows: "For stores and materials, tools, for repair of machinery and steamers' boilers, instruments, and labor in Navy Yards, and repair of machinery, and purchase of stores and material for vessels of squadrons on foreign stations;

and for transportation of material." Comparison of that wording with the legal duties as defined by the Secretary of the Navy, makes it apparent that no funds were appropriated for "designing, building, fitting out, . . . of the steam machinery used in naval vessels." The reason for this is not hard to find. The United States had gone into a typical post-war shipbuilding stasis. No new vessels were being authorized and those which had been started during the war but not completed at its end were left to rot on the stocks.

As a sidelight on what can be accomplished under such conditions, the definition of "repair" was so broadly interpreted that wartime ships were completely rebuilt as comparatively modern vessels. The rebuilt vessel retained the name of the older one and nothing else—not even its military characteristics.

The appropriation description of the duties of the Bureau of Steam Engineering were changed from time to time by change of wording, additions, and deletions. They have never been broadened to cover provision of funds for the design and new construction functions of the Bureau.

Delivery from the shipbuilding hiatus which followed the Civil War was spasmodic. The first new vessels authorized were two ironclad torpedo boats in 1871. They were authorized by inclusion in the Appropriation Act for the fiscal year 1872 of $600,000 for their construction under the head of the Bureau of Ordnance. Search of the correspondence at the time reveals that the Chief of the Bureau of Ordnance was directed to pay all bills for the hull plate upon certification by the Chief Constructor. It is probable that similar instructions were issued as regards the engineering plant. At any rate, under whatever circumstances the bills were paid, the Bureau of Steam Engineering had full control of the procurement and installation of the machinery.

In 1873 construction of eight vessels of war using auxiliary sail power with a limit of cost for the eight was authorized. All of the funds for the purpose, namely, $3,200,000, were included under the head of the Bureau of Construction and Repair Appropriation for the fiscal year 1874. Notwithstanding the location of this appropriation, a letter has been discovered in the files wherein the Secretary of the Navy directed the Engineer-in-Chief to submit his

proposals for machinery for the eight vessels directly to the Secretary, with no reference to the Bureau of Construction and Repair. There is no reason for doubting that the Bureau of Steam Engineering had full, independent control of its own responsibilities in connection with the designing, building, and fitting out of the steam machinery of these eight vessels.

Under the few provisions for new vessels which have been mentioned above, the Navy was rapidly approaching a state of desuetude. Its inevitable but bitterly opposed resurgence began about 1882. In that year the duties of the Bureau of Steam Engineering were defined by Navy Department circular as "all that relates to design, building, fitting out, repairing, and engining of the steam machinery for the propulsion of naval vessels, and will also include steam pumps, steam heaters and connections, and the steam machinery for actuating the apparatus by which turrets are turned." This circular again repeated the paragraphs, "It shall make all the contracts for and superintend all the work done under it," and "it shall estimate for and pay from its own funds the cost necessary to carry out those duties as above defined." The Appropriation Bill passed at that time, for the fiscal year 1883, authorized the use of regular funds for beginning construction of two steam vessels of war and also for proceeding with work on five double turreted Civil War monitors which had never been completed. This provision was ineffective in that there was insufficient money in the regular appropriation to permit using any of it for this purpose. The act did, however, establish a "Naval Advisory Board," which was to "advise and assist the Secretary of the Navy, in his office or elsewhere, in all matters referred to them by him relative to the design, models, plans, specifications, and contracts for such vessels in all their parts, and relative to the materials to be used therein, and to the construction thereof, and especially relative to the harmonious adjustment respectively of their hulls, machinery, and armament; . . . but said Board shall have no power to make or enter into any contract or direct or control any officer of the Navy or Chief of any Bureau of the Navy or any contractor. . . ."

The following year the appropriation, "Increase of the Navy" was first instituted. It read, "To be applied by the Secretary of the Navy under the appropriate Bureau; for engines and ma-

chinery for the double-turreted, ironclads in accordance with the recommendations of the National Advisory Board, . . . for the construction of the steel cruiser . . ., two steel cruisers . . ., and one dispatch boat as recommended by the Naval Advisory Board . . ." The vessels hereby authorized were the double-turreted monitors—*Monadnock, Puritan, Amphitrite,* and *Terror,* and the *Chicago, Boston, Atlanta,* and *Dolphin.* The first four were presumably Civil War vessels to be completed. Actually they retained the names which they had borne on the building ways for twenty years, but were relaid in different locations and rebuilt under entirely different specifications. The eight vessels were the first increments in the " New Navy."

As stated, the Increase of the Navy money for the construction of the *Chicago, Boston, Atlanta,* and *Dolphin* was appropriated under one head for application by the Secretary of the Navy under the appropriate Bureaus. The attitude of Congress toward this appropriation was disclosed to a certain degree by an interim appropriation bill which was made necessary by a delay in the passage of the regular appropriation act for the year 1885. This interim bill in addition to providing for the continuance of the regular appropriations under the various Bureaus provided for continuing work on the four ships under five different heads which, while not earmarked for the cognizant bureaus, exactly paralleled the cognizance of those bureaus as follows:

(*a*) " For continuing work upon the three new steel cruisers and one dispatch boat . . .": Bureau of Construction and Repair.

(*b*) " For completion of steam machinery and boilers with necessary fittings for sea service of steel cruisers and dispatch boat . . .": Bureau of Steam Engineering.

(*c*) " For completing outfits of three new cruisers and dispatch boat . . .": Bureau of Equipment.

(*d*) " For navigation outfit of four new steel cruisers . . .": Bureau of Navigation.

(*e*) " For ordnance outfit of three new steel cruisers and one dispatch boat . . .": Bureau of Ordnance.

Appropriation for the fiscal year 1886 added to the wording of the Construction and Repair appropriation " and completion of vessels on the stocks," and to that of the Bureau of Steam Engineering

"Completion and preservation of machinery and boilers, including steam steerers, steam capstans, steam windlasses, etc., in vessels on the stocks." However, to prevent any extensive building of ships which had been originally undertaken during the Civil War, under this provision a condition was inserted that no repairs to any wooden vessel would be made if the cost of the repairs exceeded 20 per cent of the cost of a new similar vessel. Advantage was not taken of this wording which would have permitted the two bureaus to use their regular funds for completion of ships already started; so that the inclusion for a short time of the authority to spend its money to carry out its New Construction functions bore no fruit in the Bureau of Steam Engineering. The same act included "Increase of the Navy" money for the construction, exclusive of armament, of four new vessels. The appropriation "Increase of the Navy" for this year first definitely divided the "Increase of the Navy" appropriation into two parts, one for hull and machinery, the other for armament and ammunition. This division continued until 1891 when two more heads were added under the appropriation "Increase of the Navy." These were for the Bureau of Equipment and the Bureau of Yards and Docks. The funds for the new construction functions of the Bureaus of Construction and Repair, and Steam Engineering were still combined.

Up to this point the amounts to be appropriated under the heading of Construction and Machinery were arrived at by a study of the estimates submitted to Congress by the Secretary of the Navy. Until 1891 every one of these estimates submitted was broken down into the component parts—hull, machinery, equipment, armor and armament. For some reason which the correspondence files, reports of the bureaus, reports of the Secretary of the Navy, and reports of Congressional Committees do not disclose, the "Increase of the Navy" appropriations were divided in accordance with the bureau cognizances, except that those under the cognizance of the Bureaus of Construction and Repair and Steam Engineering were always combined under the heading, Construction and Machinery. This seems to have had no effect on the independent functioning of the two Bureaus since each had estimated its own needs. These estimates were separately considered by the Secretary of the Navy and Congress, and the amounts appropriated were

easily divisible so that each of the Bureaus was left free to exercise independent control of all of its functions.

In 1891 occurred the first of several changes which eventually led to the condition which existed in 1936 and which will be described later. In that year the Secretary of the Navy, in submitting the Increase of the Navy estimates to the Congress, for the first time submitted the "Construction and Machinery" estimate as one figure. The Bureaus jointly had submitted the figure to him in two parts. The procedure was for the Bureau of Steam Engineering to submit its estimate of money needed for all matters under its cognizance on ships under construction or previously authorized, to the Bureau of Construction and Repair. This Bureau then prepared the estimates in the following form:

	Bureau of Construction and Repair	*Bureau of Steam Engineering*	*Increase Navy Construction and Machinery*
Vessel A	$.....	$.....	$.....
Vessel B	$.....	$.....	$.....
Etc.	$.....	$.....	$.....
Total	$.....	$.....	$.....

for submission to the Secretary by joint letter. Previously to 1891 the Secretary had transmitted these estimates in that same form, but in that year he omitted the Construction and Repair—Steam Engineering breakdown and submitted only the total "Increase of the Navy" figures. Starting from this year Congress was never furnished with the separate estimates of expenditures of the two Bureaus and did not obtain these figures unless a member of a Congressional Committee happened to ask one of the Bureau Chiefs.

A second change occurred in 1913 when the Bureaus jointly reported the estimates for "Increase of the Navy" as one lump figure. After that date the Secretary of the Navy was no longer aware of the proportion of the total estimates for new construction under the cognizance of the Bureau of Steam Engineering or the Bureau of Construction and Repair. The estimates were still prepared separately, but combined into one figure when the joint estimate was prepared for submission to the Secretary.

The third change occurred in 1922 when the Bureau of Engineering (new name) ceased to make any estimates. From that date until about 1936, the estimates for new construction under the appropriation, "Increase of the Navy" and later under "Replacement of Naval Vessels" were made entirely by the Bureau of Construction and Repair as a "Construction and Machinery" estimate. There was no breakdown of this estimate, whatever, into matters under the cognizance of the two Bureaus.

Summarizing the above three changes which completely eliminated any independence which the Bureau of Engineering had had, the first change presented the hull and machinery costs of ships to Congress as one figure, the second presented it to the Secretary of the Navy as one figure, and the third reduced it to one figure for all hands. However, during the whole period until 1922, the two Chiefs of Bureaus retained complete control of expenditure of money for matters under their cognizance; and, in presenting estimates to Congress, both Chiefs were interrogated separately by the Committees and each was held and considered responsible for enunciation of technical policies for which he was responsible.

The final change which occurred in 1922 was brought about largely by the passage of the Budget and Accounting Act of 1921. Cursory search of the records reveals no definite reason for the previous changes. The changes were made and their result was a gradual weakening of the independence which the Chief of the Bureau of Engineering should have enjoyed to have permitted him properly to discharge his responsibilities. By inference, it may be assumed that the changes were brought about through an aggressive policy prosecuted by a succession of Chief Constructors and tacitly accepted by a succession of Engineer-in-Chiefs who were more interested in technical engineering matters than in fiscal policies or questions of technical authority.

The Accounting Act of 1921 established the Federal Bureau of the Budget, a Navy Department Budget Officer, and a budget officer in each office or bureau which had a separate appropriation. By agreement, acceded to apparently with no hesitation by the incumbent Engineer-in-Chief, all records in connection with the appropriation "Increase of the Navy, Construction and Machinery" were left in the Bureau of Construction and Repair. The

Engineer-in-Chief retained only indirect control. He even agreed to a proposal to change the "Increase of the Navy, Construction and Machinery" appropriation from a designation which placed it under the Secretary's Office to one which placed it under the Bureau of Construction and Repair; but to this change the Navy Department did not agree. Prior to the 1922 change, each of the Chiefs of Bureau had been free not only to initiate but to sign and issue correspondence in connection with new construction matters under his cognizance. With the change which was formally agreed to in a conference in 1923, it became necessary that every piece of correspondence originating in either Bureau be signed by both Chiefs of Bureau or by designated subordinate, even though the subject matter was strictly and unquestionably a one-bureau affair.

A third vital feature, in addition to fiscal estimates and records, and correspondence, was concerned with the presentation of the estimates to the Congress. The appropriation having been made officially a jointly controlled one, the method adopted of presenting it to Committees of Congress was to have the entire statement presented by the Chief Constructor acting for both Chiefs. The Accounting Act had required that all appropriation matters be presented to a subcommittee of the Appropriation Committee rather than to the Naval Affairs Committee as theretofore. Initially, of course, the members of the Appropriation Committee were primarily, if not exclusively, interested in dollars rather than in technical matters. The natural result was that the statement and interrogation following its presentation was practically free of technical matters and restricted almost exclusively to fiscal subjects. This necessarily involved matters of administrative policy.

One-man presentation of a two-man statement to a Committee whose members were largely unfamiliar with naval affairs, naturally led those members to the belief that the man who did the talking was the man responsible. The Engineer-in-Chief became merely a spectator at the hearings, and in many cases did not contribute a single word. In fact, it appears from the printed hearings he may not even have attended some sessions.

The possible complications of this system did not become apparent for several years, due principally to the fact that the end of the war and the Disarmament Conference and Treaty of 1922 brought

naval construction almost to a standstill. Very few ships were under construction in 1923 and very few more were begun for the next ten years. The methods of administration of the joint appropriation, which had become adopted through custom, presented no difficulty until the N.I.R.A. program, authorized in June, 1933, was undertaken. Expenditures for new construction, which had reached a peak of $366,000,000 in 1919; had dropped to about $20,000,000 in 1926; had climbed back to about $40,000,000 in 1933; doubled again to $80,000,000 in 1935; reached $135,000,000 in 1936; and are expected to exceed $160,000,000 in 1939. Present rough estimates indicate that if the maximum of present plans should be adopted and followed, these expenditures will reach a peak in 1943, again doubling to a new total of about $320,000,000.

The situation which thus existed in 1936 was that a total of about $173,000,000 was expended for carrying out all of the functions of the Bureaus of Engineering and Construction and Repair. This total was made up of about $18,000,000 in the regular Construction and Repair Appropriation, about $20,000,000 under the regular Engineering Appropriation, and the remainder appropriated for shipbuilding, either under the appropriation "Increase of the Navy" or "NIRA."

Of the shipbuilding money, the accounting system in effect in 1936 is inadequate for determining what percentage was spent for matters under the cognizance of one or the other of the two Bureaus. An estimate made on the expected expenditures for 1939 is that nearly one-half of the total will be expended for matters under the cognizance of the Bureau of Engineering and the remainder for all other matters which includes minor expenditures for items under the Bureaus of Navigation, Supplies and Accounts, Aeronautics, and Medicine and Surgery as well as the Bureau of Construction and Repair.

It is a fairly safe assumption that at least half of all "Construction and Machinery" money expended for new construction is spent in carrying out the legal responsibilities of the Bureau of Engineering. Accepting that, the expenditures for matters under the cognizance of the Bureau of Engineering in the fiscal year 1936 were in the order of $86,000,000. Of this total less than 25 per cent was included in the regular Engineering Appropriation

which was directly under the independent control of the Bureau of Engineering. The Engineer-in-Chief was legally and penally responsible for the proper expenditure of that amount. The remaining 75 per cent was under joint control with the Bureau of Construction and Repair and was so accounted for and administered that no one except the Secretary of the Navy himself could have been held responsible for improper handling even though the people legally responsible under the basic law of 1862, and the current Navy Regulations based thereon, were the Chief Constructor and the Engineer-in-Chief.

The situation has been presented as though it was disadvantageous only to the Engineer-in-Chief to have the funds for carrying out three-fourths of his responsibilities subject to partial control by another official of parallel authority. Actually, the arrangement could easily be just as undesirable to the Chief Constructor.

As a typical example of what could not be done in 1936 was answering the questions: "Why does this ship cost more than an approximately similar one built two years ago?" and "Why do you now say that this ship, which two years ago you said would cost so much, will now cost so much more?" Answers to questions of both types have used comparative labor and material costs and comparative tonnage and horsepowers. Authorities who have asked such questions have had to accept general answers because no better were available. Any question of the kind can be answered if estimates are built up from detailed specifications and none can be, where the estimate is a gross one of so much per ton displacement corrected for predicted labor and material index.

Before describing the changes which have been made or initiated in the last two years, it would be well to peruse the current description of the duties and responsibilities of the Bureau of Engineering as laid down in the Navy Regulations.

The general provisions pertinent to this article are:

"The several bureaus shall retain the charge and custody of the books or records and accounts pertaining to their respective duties, and all of the duties of the bureaus shall be performed under the authority of the Secretary of the Navy and their order shall be considered as emanating from him and shall have full force and effect as such (sec. 420, R.S.).

"Chiefs of bureaus shall issue orders concerning the work of their own bureaus, provided such work is not of a character to alter the military characteristics of any ship or shore station. Any proposed work, the performance of which would alter the military characteristics of any ship or shore station, shall be referred, via the Chief of Naval Operations for comment and recommendation, to the Secretary of the Navy for decision prior to authorization.

"In every case pertaining to the design, alteration, or repair of ships or equipage or shore stations wherein any bureau recommends for approval any departure from recognized standard practice, or any action at variance with any former decision of the Navy Department, such bureau shall invite the attention of the Secretary of the Navy to—

(*a*) The previous decisions or rulings of the Navy Department in regard to the subject in question.

(*b*) The reasons for recommending any departure from existing practice or any change in policy.

"Each bureau shall determine upon and require for or have manufactured all material, apparatus, tools, stores, fuel, transportation, office supplies, and appliances of every kind needed in carrying out its duties as hereinafter defined. Each bureau shall be charged with the preservation of the public property under its cognizance.

"Each bureau shall be charged with all that relates to the equipment of ships according to its approved allowance lists.

"Each bureau shall estimate for and defray from its own funds the cost necessary to carry out its duties as hereinafter defined."

The particular provisions are:

"1. The Bureau of Engineering, under the direction of the Secretary of the Navy, is charged with and responsible for the design, construction, installation, and maintenance of all propelling machinery, together with its auxiliaries; and, except as specifically assigned to other cognizance, exterior and interior communication systems, electric wiring and cable, and auxiliary machinery, and appliances and articles of equipage on its approved allowance lists.

"2. It is charged with the design, manufacture, installation, and maintenance of all radio and sound equipage, ashore and afloat,

including all appliances; used by the Naval Communication Service, except such material as is assigned to other cognizance.

"3. It is charged with the upkeep and operation of the following laboratories: Engineering Experiment Station, Annapolis, Md.; Naval Research Laboratory, Anacostia, D. C.; Naval Boiler Laboratory, Philadelphia, Pa.; Material Laboratory, Navy Yard, New York (joint cognizance with the Bureau of Construction and Repair), and with their repairs, except as excluded in article 848.

"4. It shall prepare specifications for fuel and be responsible for its inspection.

"5. When not prescribed by the United States Navy Regulations, specific assignment of cognizance will be stated in the Manual of the Bureau of Engineering."

Funds are specifically appropriated to the Bureau of Engineering for purposes described as follows:

"For repairs, preservation, and renewal of machinery, auxiliary machinery, and boilers of naval vessels, yard craft, and ships' boats, distilling and refrigerating apparatus; repairs, preservation, and renewals of electric interior and exterior signal communications and all electrical appliances of whatsoever nature on board naval vessels, except range finders, battle order and range transmitters and indicators, and motors and their controlling apparatus used to operate machinery belonging to other bureaus; searchlights and fire-control equipments for antiaircraft defense at shore stations; maintenance and operation of coast signal service; equipage, supplies, and materials under the cognizance of the Bureau required for the maintenance and operation of naval vessels, yard craft, and ships' boats; purchase, installation, repair, and preservation of machinery, tools, and appliances in navy yards and stations, accident prevention, pay of classified field force under the Bureau; incidental expenses for naval vessels, navy yards, and stations, inspectors' offices, the engineering experiment station, such as photographing, technical books and periodicals, stationery, and instruments; services, instruments, machines and auxiliaries, apparatus and supplies, and technical books and periodicals necessary to carry on experimental and research work; maintenance and equipment of buildings and grounds at the engineering experiment station, Annapolis, Maryland; payment of part time or intermittent employment in the

District of Columbia or elsewhere of such scientists and technicists as may be contracted for by the Secretary of the Navy, in his discretion, at a rate of pay not exceeding $20 per diem for any persons so employed; . . ."

The appropriation provides for carrying out all of the specific duties of the Bureau of Engineering except:

". . . responsibility for the design, construction, installation . . . of all propelling machinery, together with its auxiliaries; and except as specifically assigned to other cognizance, exterior and interior communication systems, electric wiring and cable, and auxiliary machinery, and appliances and articles of equipage on its approved allowance list."

This portion of the duties of the Bureau of Engineering is appropriated for under the appropriation "Replacement of Naval Vessels, Construction and Machinery," as follows:

"Construction and machinery: . . . and machinery of vessels heretofore authorized (and appropriated for in part), and for the commencement of the following vessels . . . to remain available until expended: . . . Provided further, That, of the appropriations made available by this Act under the head of "Replacement of naval vessels," there shall be available such sums as the Secretary of the Navy may from time to time determine to be necessary for the engagement of technical services, and the employment of personnel in the Navy Department and in the field, the purchase of plans, drafting and other supplies, and the expenses of printing and travel, in addition to those otherwise provided for, owing to the construction of vessels which have been, or may hereafter be authorized.

. . . . . .

"The appropriations made in this Act for the purchase or manufacture of equipment or material or of a particular class of equipment or material shall be available for the purchase of letters patent, applications for letters patent, licenses under letters patent, and applications for letters patent that pertain to such equipment or material for which the appropriations are made. . . ."

This latter part of the Bureau of Engineering's duties constituted about 80 per cent of the total in 1936 and is estimated to be about 75 per cent in 1939 and may reach 85 per cent or more in 1943.

Approximately the same figures are applicable to the Bureau of Construction and Repair, yet both Bureaus are denied absolute control of their portions of the money. Under the joint control, each Bureau must either "rubber-stamp" every action of the other or must duplicate the machinery for handling. In 1936 it was all "rubber stamp" with the Bureau of Construction and Repair exercising the same control over money estimates, allocations, and expenditures as it did over hull plating.

Of the general duties of the Bureau of Engineering cited above, the first—"the several bureaus shall retain charge and custody of the books of records and accounts pertaining to their respective duties," had been neglected and it was turned over exclusively, as regards the Bureau of Engineering portion, to the Bureau of Construction and Repair.

The second—"Chiefs of Bureaus shall issue orders concerning the work of their own bureau . . ." etc., was violated in that neither of the two Chiefs could issue an order independently.

The last—"Each bureau shall estimate for and defray from its own funds the cost necessary to carry out its duties as hereinafter defined" was disregarded by the Bureau of Engineering as regards estimates; and for three-fourths or more of its duties each of the two bureaus could not carry them out because neither had any funds. Each had to draw on a common, undivided, fund which happened to be largely under the control of one of them.

The principal defects of the system in 1936 are contained in the three preceding paragraphs. Since that date, machinery has been set up for making all engineering estimates in the Bureau of Engineering and maintaining records of all Engineering obligations and expenditures. Unfortunately the latter entails double records; since it is essential, under the necessities imposed by the regulations and by actually existing conditions, that the Bureau of Engineering maintain records of engineering money as well as to duplicate, in effect, the Construction and Repair records of "Construction and Machinery" money.

Opinion in the informed part of the Navy is divided as to whether the present situation is satisfactory or not. On the side of the former it can be said that the Navy is managing to build ships and pay for them and that there has been no question raised that funds are being illegally or improperly (in a moral sense) handled.

The opposition's arguments, in part, are: That the law as defined by the Navy Regulations is being violated; that costs of new vessels appear to be unreasonably high and the analysis of the reasons is impossible; that delays are incurred with no clear-cut responsibility, hence no responsibility since the American idea of justice does not permit hanging two suspects even when it is known that at least half of the execution is proper; that neither Chief of Bureau can independently discharge his legal duties; that either is in a position to interfere with the other and occasionally one does; and that joint control usually means rubber stamping by one Bureau of the actions of the other with a resultant delay in all correspondence.

There are three possible ways of changing the present system to improve it. These are:

(*a*) Rewrite the Regulations so that they cover the situation as it actually exists at present.

(*b*) Reorganize the Navy Department to provide for an Administrator of Shipbuilding who would administer the appropriation "Replacement of Naval Vessels" with the Chiefs of the material bureaus as assistants, and revise the Regulations to conform.

(*c*) Maintain the present organization and retain the present wording of the Regulations by merely dividing the appropriation "Replacement of Naval Vessels" among the Bureaus by allotment or allocation granted by the Secretary of the Navy.

Actually, method (*a*) would not improve the situation at all. It would eliminate any violations or near violations of the Regulations, and that is all. If, in a community, crime exists and can not be curbed; the proper solution is not to repeal the statutes which define the crimes.

Method (*b*) has had proponents at various times in the past, and doubtless many can be found at the present time. It would probably be found to operate satisfactorily in practice, but would in effect be nothing more than an additional appendage to the present organization. That is, the Administrator of Shipbuilding could not be a technical man thoroughly familiar with the problems of all of the material bureaus. There are no such individuals. He would merely be an Administrator and would occupy in the proposed organization exactly the same position which the Secretary of the

Navy now occupies in connection with shipbuilding. He would relieve the Secretary of the necessity of making decisions, but all of the problems which now exist under the Secretary would still exist under him.

Method (*c*) is the only one of the three which offers a real, practicable solution. It would recognize the present organization and the present Regulations. Basically both of these have stood for over 75 years. They have carried the Navy through two major wars and several skirmishes. All that this method would do would be to set up a mechanism whereby each of the naval officials concerned would be given full control of all of the tools which he uses and requires for discharging his regular responsibilities.

METHODS AND MEANS FOR DETERMINING THE NATURAL MODES OF VIBRATION OF MECHANICAL STRUCTURES.

By H. C. Hayes,* and Elias Klein.†

Cyclic strains in vibrating mechanical structures often lead to failures because of the resulting fatigue of the material. Both theory and practice indicate that the breaks or other types of failure occur at a node of one of the numerous natural modes of vibration of the structure. These natural modes of vibration can be determined theoretically if the structure is simple and the parts are of geometrical form but usually the problem is too complicated for exact solution and the best that can be hoped for from theory is a rough approximation of the resonant frequencies and a still rougher approximation of the location of the nodes of the vibrating system. The present paper describes a simple method and means for experimentally determining the several natural resonant frequencies of any mechanical system and the location of the nodes of their respective standing wave systems. Its effectiveness is demonstrated by analyzing three modes of vibration of a ship's propeller.

The resonant frequencies of the system are determined by applying an oscillating force to some relatively heavy and concentrated mass in the system—to which also a sensitive vibration detector is attached—and slowly varying the frequency of the oscillating force over the range to be investigated. The resonant frequencies are indicated by a response of the detector. The nodes are located by means of the phase relation between the voltage response of the fixed detector and a second similar detector that can be moved about over the structure. The phase suddenly shifts 180 degrees when the movable detector crosses a nodal line.

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† Physicist, Naval Research Laboratory, Anacostia Station, D. C.

The oscillating force is conveniently supplied by a coil-surrounded rod or tube of magnetostrictive material, one end of which attaches to the structure and the other to a concentrated mass. The coil is preferably supplied with both direct and alternating current so proportioned that the magnetic polarity of the rod or tube is not reversed. Under these conditions the oscillating frequency of the magnetostrictive element equals the frequency of the supplied alternating current. Without the direct current polarizing current the bar oscillates at double the impressed alternating current frequency.

The vibration detectors can be either a displacement, velocity or acceleration type depending upon the frequency of the vibrations to be investigated. In general, the acceleration type is preferred because less care is required in handling.

In practice the voltage terminals of the two detectors are connected respectively across the two pairs of plates of a cathode ray oscillograph with such intervening amplification as may be required to deflect the cathode beam.

Alternating current power for the magnetostrictive element is supplied by a variable frequency vacuum tube oscillator operating through a power amplifier. Two hundred watts alternating current is sufficient to oscillate most structures. In fact, 20 watts will oscillate most structures having a low damping coefficient.

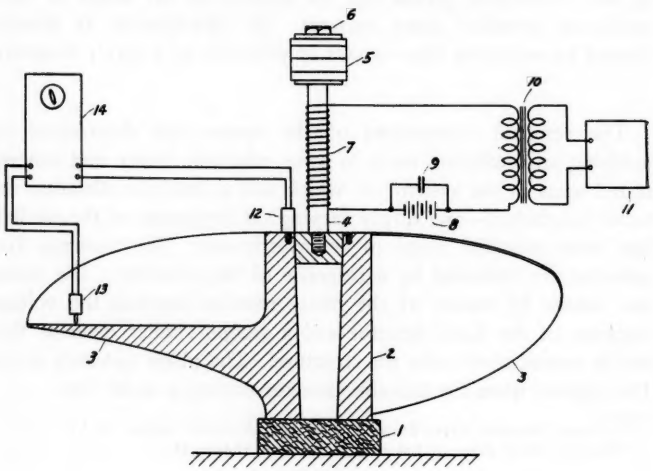


FIGURE 1.

Figure 1 shows schematically the set-up for oscillating a ship's propeller wherein (1) is a felt pad on which the hub (2) of the propeller carrying blades (3) is flexibly mounted. Magnetostriction element (4) threads firmly into a core driven into the hub and carries masses (5) at its upper end which are clamped by nut (6). The surrounding coil (7) is energized by direct current from battery (8) having a bypass condenser (9) and is supplied alternating current through transformer (10) from oscillator and amplifier (11). Vibration detector (12) attaches to the hub and detector (13) can be moved about over the blades. These detectors connect respectively with the two pairs of plates of cathode ray oscillograph (14).

Figure 2 is a photograph of the propeller with the attached oscillation element and its surrounding coil. The diameter of the propeller is 7 feet 4 inches and its weight is 2990 pounds. The mass anchored to the top of the element consists of lead discs and can be varied from 10 to 100 pounds in steps of 12 pounds. The fixed vibration detector can be seen attached to the hub and the movable one is held on one of the blades. The power source, which consisted of a beat frequency oscillator and power amplifier, and the cathode ray oscillograph are not shown.

The propeller with the attached oscillator element forms a coupled system of two degrees of freedom and can be represented schematically as in Figure 3 wherein (O) represents the mass concentrated at the upper end of the oscillator element, (H) the mass

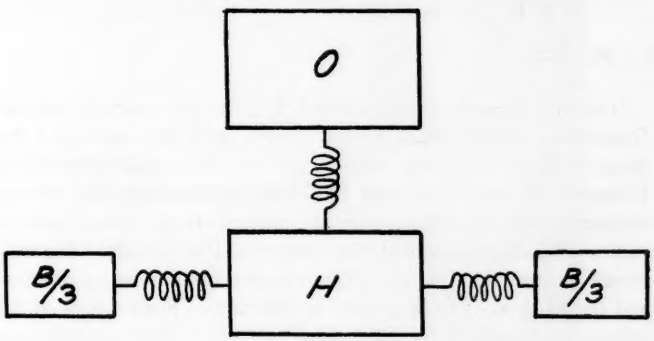


FIGURE 3.

concentrated at the propeller hub and (B) the concentrated mass of the blades. Such a system has two resonant frequencies neither of which is equal to the resonant frequency of (O) and (H) with (B) detached or to (H) and (B) alone with (O) detached. This latter is the resonant frequency of the propeller alone and hence the frequency in which we are interested.

But theory shows that the coupled resonant frequencies approach the uncoupled ones more and more closely as the value of the expression

$$\frac{O \times B}{(O + H) \times (H + B)}$$

approaches zero. This mathematical expression is the coefficient of coupling of such an oscillating system. In the tests to be described, the values of the involved masses were as follows:

$$O = 10\text{-}100 \text{ pounds}$$

$$H = 1290 \text{ pounds}$$

$$B = 1700 \text{ pounds}$$

$$\text{Max } (O + H) = 1390 \text{ pounds}$$

$$\text{Max } (H + B) = 2990 \text{ pounds}$$

$$\therefore \frac{O \times B}{(O + H) \times (H + B)} \text{ max.} = \frac{100 \times 1700}{1390 \times 2990} = .046 =$$

4.6 per cent.

It should, therefore, be expected that the two coupled resonant frequencies would coincide very closely with the uncoupled frequencies because of this small value of the coupling coefficient. However, to make sure that this would prove true, the resonant frequencies of the system were determined using several different values of (O) throughout the range 25-100 pounds. Figure 4 shows the test data plotted with resonant frequencies as abscissae and the mass of (O) in pounds as ordinates. Four values of frequency are tabulated for each value of (O). Three of these rep-

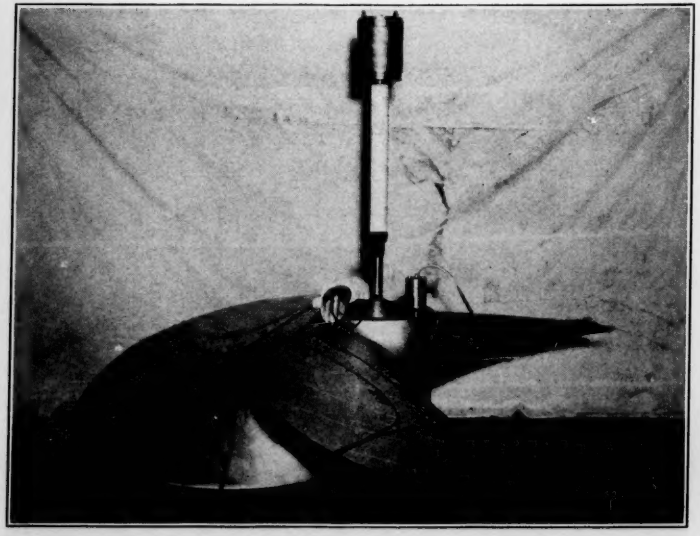


FIGURE 2.

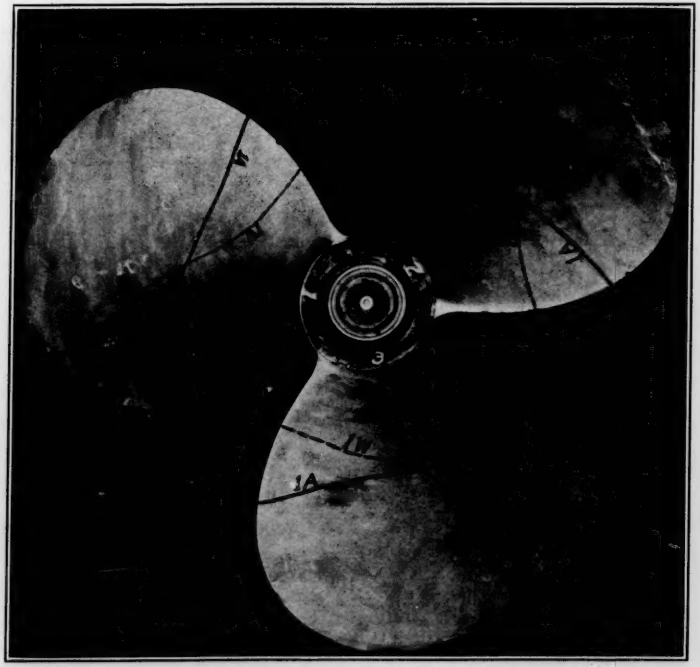


FIGURE 5.

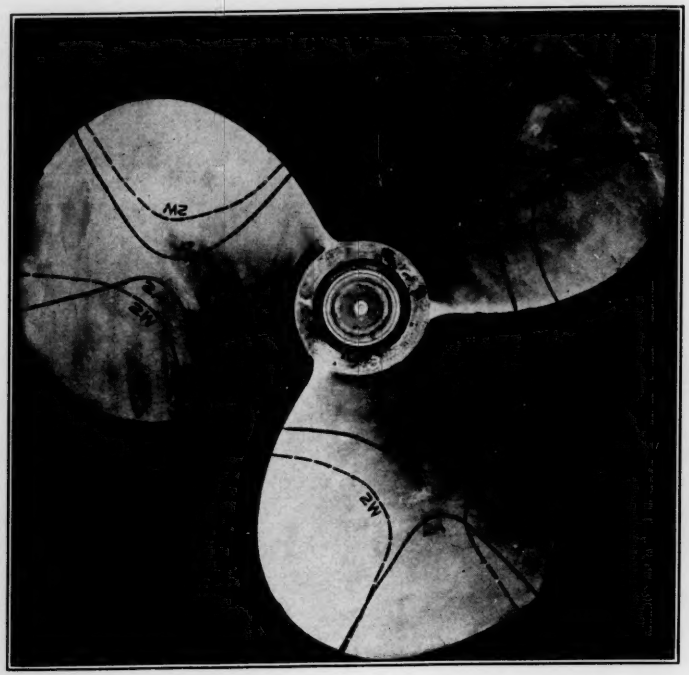


FIGURE 6.

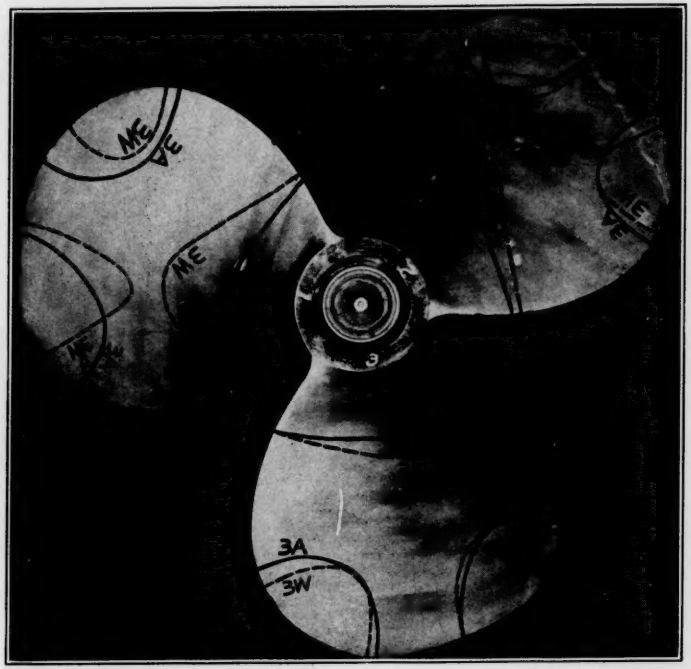


FIGURE 7.

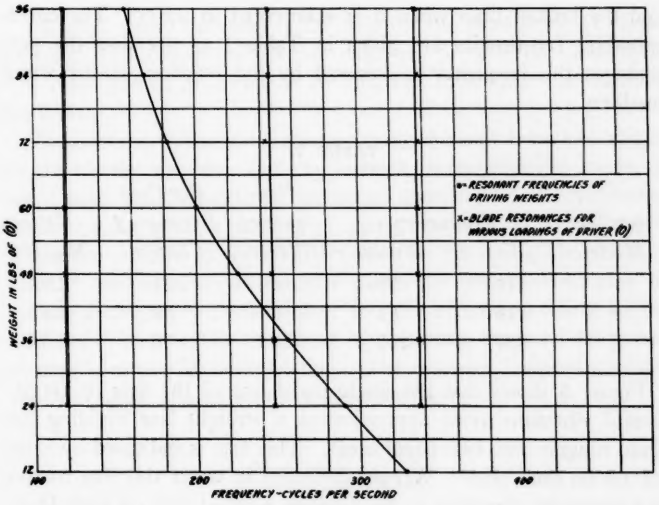


FIGURE 4.

resent the three modes of vibration of the propeller blades that are to be investigated and the fourth represents the resonant frequency of the weight (O) and the propeller connected by the elastic magnetostrictive member. The data referring to the first, second, and third mode of blade vibration lie on three vertical lines of frequency; 119, 246, and 337 c.p.s. respectively. The fourth curve, giving the frequency between the propeller and driving mass (O), is expressed by the equation

$$N = 159 \sqrt{\frac{93}{(O)}}$$

to within the accuracy of the test measurements. It, therefore, follows that the frequencies measured and recorded do not differ from the uncoupled frequencies by more than the errors of measurement which, depending upon temperature conditions, may be as much as three per cent. Figures 5, 6, and 7 show the location of the nodal lines for the first, second, and third modes of vibration respectively. The solid lines obtain when the propeller is in air

FIGURE 6.

and the broken lines when it is submerged in water. The corresponding frequencies are given in Table 1 as are also the percentages the frequency is lowered by the reaction of the water medium.

TABLE 1.

Vibration Mode	*Frequency*		*Frequency Difference*	*Per Cent Frequency Change*	*Ratio* M_W/M_B
	Air	*Water*			
1	119	70	49	41	1.89
2	246	151	95	38	1.65
3	337	215	122	36	1.46

Figure 5 shows that the single nodal line of the first or fundamental vibration mode approximates a straight line dividing the blade roughly into two equal areas. This line is indicated by symbol 1A on each blade. When submerged in water this line rotates in a clockwise direction to the position marked 1W on each blade and the loading and damping of the water lowers the resonant frequency 41 per cent. Figure 6 shows the two nodal lines of the second mode of vibration. When in air they take the position of the solid lines labeled 2A and shift to the broken lines 2W when the propeller is submerged.

It may be noted that the open space between the solid 2A lines on blades 1 and 2 extends in a radial direction and on blade 3 it takes a circumferential course, while in case of the 2W lines the open space extends radially on all three blades. This is probably accounted for by the added loading on the outer tip portions of blades 1 and 2 for purposes of dynamic balance. Blade 3 has no such loading as can be seen in the photograph. Except for this relatively slight loading the nodal pattern of blades 1 and 2 would probably have resembled that of blade 3 in that the opening between the 2A lines would have been directed circumferentially. This explanation seems still more plausible when it is noted that the opening between the 2W lines extends radially on all three blades. The water loading is sufficient to offset the relatively small inequality of loading in air and make all the blades substantially alike. This indicates that the water loading is relatively large.

Figure 7 shows the three nodal lines for the third mode of vibration and their change of position when the propeller is submerged. The lines labeled 3A refer to air and 3W to a water surrounding medium.

The lowered frequencies when submerged result from two effects of the heavier medium; first, by increase in the effective inertia of the blades, and second, by increased damping of the vibrations caused by the greater amount of energy radiated as sound waves. From the relative magnitude of these two effects as computed by Lamb,* for rim-clamped circular plates the inertia effect may be expected to greatly predominate, and the effective loading of the blades can be roughly calculated by assuming the total frequency change is caused by such loading. The resonant frequency of any mode of blade vibration can be expressed as

$$N = \frac{1}{2\pi}\sqrt{\frac{S}{M}}$$

where (N) is the resonant frequency, (S) a spring factor, and (M) an effective mass. The loading in air can be regarded as zero in comparison with that of water and the spring factor (S) may be regarded as independent of the medium. Therefore:

$$(1) \qquad N_A = \frac{1}{2\pi}\sqrt{\frac{S}{M_B}}, \text{ and}$$

$$(2) \qquad N_W = \frac{1}{2\pi}\sqrt{\frac{S}{M_B + M_W}}$$

where (M_B) represents the effective mass of the bronze, (M_W) the effective mass of the water loading and (N_A) and (N_W) the resonant frequencies in air and water respectively. Squaring and dividing (1) by (2) gives

$$(3) \qquad \frac{N_A{}^2}{N_W{}^2} = \frac{M_B + M_W}{M_B}$$

* Roy. Soc. Proc. 98, 205 (1920).

Therefore

$$(4) \qquad \frac{M_W}{M_B} = \left(\frac{N_A}{N_W}\right)^2 - 1$$

Thus the effective water loading on the blades in terms of the effective mass of the blades for each mode of vibration is given by inserting the respective values of (N_A) and (N_w) from columns (2) and (3) of Table 1. These values, which are tabulated in column (6), are offered only as a rough approximation of the actual water loading on a propeller operating under service conditions. In the first place, as stated, the effect of damping has been neglected and secondly, the propeller was submerged in a cylindrical tank only one foot greater in diameter and height than the corresponding dimension of the propeller. The effective loading will doubtless be somewhat greater in open water. Studies in progress are designed to throw more light on the actual water loading of propellers.

FIFTY YEARS OF NAVAL ENGINEERING IN RETROSPECT.

PART IV.

1921–1938.

By Herbert M. Neuhaus, Member.*

This article is the fourth and last of a series wherein the author has drawn from the Journal *a Retrospect of the five decades of rich experience which is the heritage of the American Society of Naval Engineers. In 1888, at the time of the formation of the Society, steam motive power was superseding sails, double expansion engines were replacing the old single expansion engines, scientific achievement had expanded beyond the limits of pure science and was adapting itself to useful engineering. The following years brought the triple expansion engine, reaction and impulse turbines, reduction gears, oil as fuel, the water tube boiler, artificial refrigeration, a great expansion of electrical adaptations, radio, and electric main propulsion. The United States, in 1917, entered the maelstrom of the World War, engaged in the mass production of ships, and at the end of the War found itself in the midst of constructing the world's largest merchant fleet and the world's most powerful battle fleet. Other countries carried on competitive programs. The fourth period commences in the midst of this great rush of naval construction.*

A change in the naval engineering horizon is at once in evidence at the start of the period under discussion. Gargantua appear as the order of the day in military weapons. Following upon the heels of the World War the tension and attrition incident to the German submarine campaign had completely subsided and the leading maritime nations again directed their energies to the build-

* Associate Mechanical Engineer, Design Division, Bureau of Engineeering.

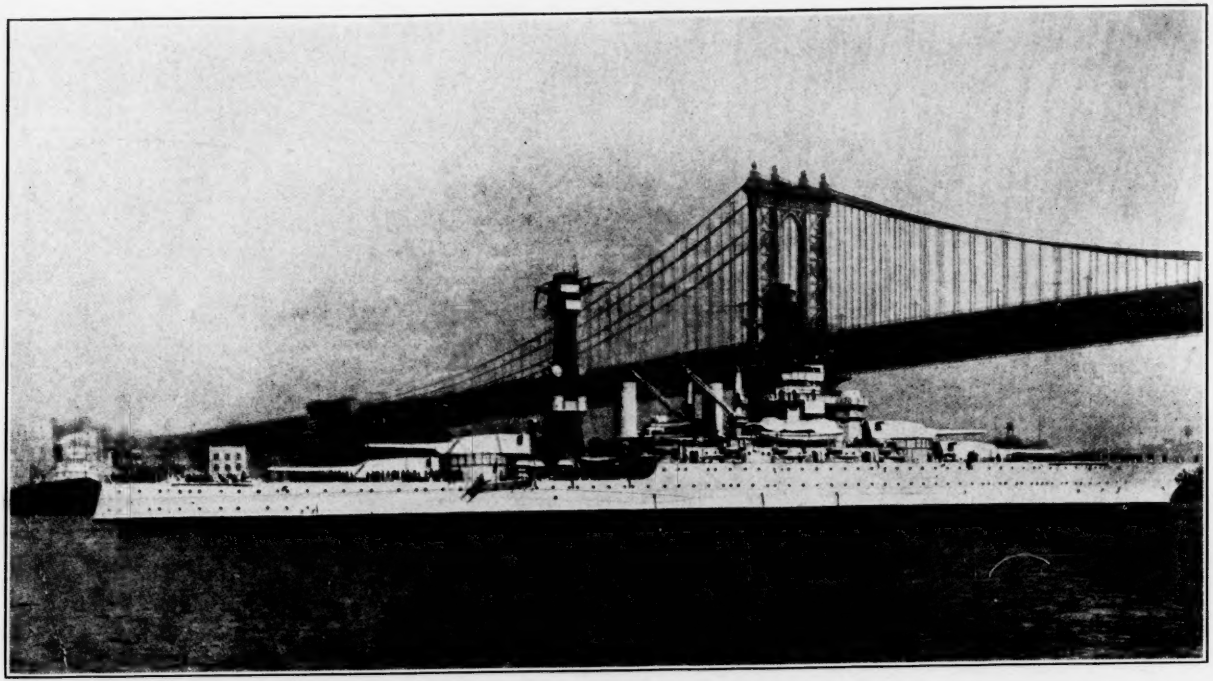
ing of battleships and battle cruisers. Due to heavy losses from undersea warfare, construction activity had temporarily been diverted to the building of small fast vessels for escort duty and to hunt down submarines. The United States now possessed almost three hundred destroyers in addition to several converted yachts, Eagle boats, and wooden submarine chasers. This latter construction was stopped and diverted into the building of major ships, of which this country had underway six battle cruisers of 43,500 tons and 180,000 horsepower under "cost-plus" contracts or at navy yards, two 32,500-ton 14-inch gun battleships of 28,000 horsepower, four 32,500-ton 16-inch gun battleships of 28,000 horsepower, six 43,200-ton 16-inch gun battleships of 60,000 horsepower, and ten 7500-ton light cruisers of 90,000 horsepower.

At this point in our history we must divert our attention from its engineering aspect to one of diplomacy. Fearing another severely competitive period of naval construction similar to that preceding the War just closed, the President of the United States invited the leading maritime nations of the world to a conference at Washington, D. C., for the purpose of discussing limitation of armaments. For this article only the purely naval aspects of the ensuing treaty will be considered. In addition to the United States, England, Japan, France, and Italy participated, resulting in the famous 5:5:3:1.5:1.5 ratio of capital ship construction. Apparently even this was not satisfactory as a yardstick, leading journalists in the countries concerned complaining of selling their individual birthrights. For the first time definite limits were placed on certain categories of vessels, a problem until then unsolved.

Concessions were made by all. At the outset of the conference two principal bargaining groups formed automatically, the first being England, Japan, and the United States, and the second being France and Italy competing between themselves. The major points evolved by the conference and finally incorporated in the treaty were as follows:

(*a*) Capital ships were defined as vessels of war, not aircraft carriers, exceeding 10,000 tons standard displacement or carrying a gun of more than 8-inch caliber. 525,000 tons each were allowed to the United States and England, with a maximum individual replacement of 35,000 tons. On retained ships 3000 tons

U. S. S. "Richmond."
Figure 1.



U. S. S. "MARYLAND."
FIGURE 3.

additional were allowed for defense against air and submarine attack, no other alterations, and a maximum of 16-inch gun caliber. Age limits of 20 years were specified.

(*b*) Aircraft carriers were limited to a total of 135,000 tons, the maximum tonnage of one vessel being 27,000 tons, except that two vessels of 33,000 tons were permitted provided the total allowance was not exceeded, no guns to be over 8 inches.

(*c*) Cruisers were limited to 10,000 tons with a maximum gun caliber of 8 inches, no limitation as to total tonnage.

(*d*) The treaty provided for an exchange between the signatory powers of the names of new vessels, vessels to be replaced, dates of authorization and keel laying, general characteristics such as displacement, dimensions, and armament. A saving clause in case of loss or accidental destruction was also provided.

(*e*) Standard displacement of a ship was defined as that of a ship complete, fully manned, engined, and equipped ready for sea, including all armament and ammunitions, equipment, outfit, provisions, and fresh water for crew, miscellaneous stores and implements of every description that are intended to be carried in war, but without fuel or reserve feed water on board. Tons were understood to mean a ton of 2240 pounds.

U. S. S. "MARYLAND."
FIGURE 3.

This treaty came into force on August 17, 1923, and remained in force until December 31, 1936. In the event none of the contracting powers gave notice two years before its termination, it was to continue in force for two years following such notification and then was to terminate as regards all the contracting powers.

However, before the Washington Treaty sounded the death knell of major warship building, a series of ships and engineering plants appeared on the roster to serve as standards for several years. First of these ships was the light cruiser *Omaha,* which was launched in December, 1920. Built as an entirely new type, she marked a new era in cruiser building. In general appearance the group (Figure 1) of which the *Omaha* was representative resembled an enlarged destroyer with a straight stem and considerable sheer to its bow. Four smokepipes and a severe rake to the weather deck completed the resemblance. Displacement was 7500 tons, length 550 feet, and beam 55 feet. The 90,000-horsepower geared-turbine installation on four shafts featured the highest powered machinery plant ever placed in one of our naval vessels.

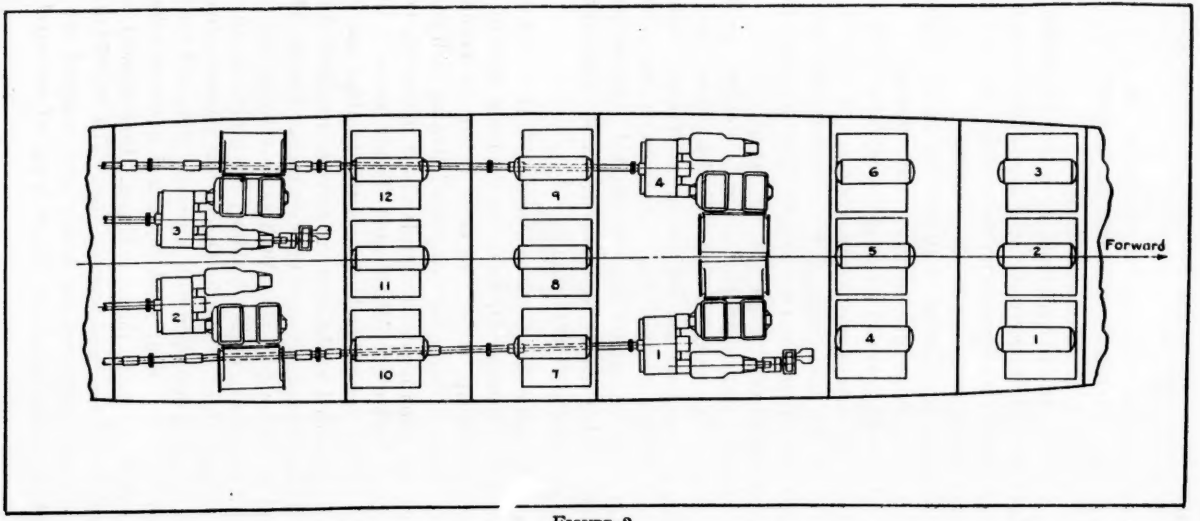


FIGURE 2.

Six Yarrow boilers in two sizes in two compartments (Figure 2) supplied steam to four geared turbine units, each consisting of a high and low-pressure turbine coupled to the main shafts through Westinghouse-MacAlpine reduction gears. For cruising speeds up to 17.5 knots a cruising turbine and cruising reduction gear with positive clutches were supplied. The gears were the first to be used as main reduction gears by being interposed between the propeller shaft and the main turbines, other than those used in destroyers and in the *Neptune*. (Note—In Article III of this series an error was made in stating that the *Pennsylvania* was the first completely geared battleship installation. The *Pennsylvania* was fitted with cruising reduction gears only as were the *Idaho* and *Mississippi*, which followed. No fully-geared battleship plant appeared as an original design until recently, though one of the first entirely geared turbines was placed in the *North Dakota* during her modernization in 1919.) Another interesting item on this cruiser class was the use of the Audiffren Sigrun sulfur dioxide ice machine commonly known as the "dumbell" machine.

Authorized in March, 1915, the *Tennessee* was finally launched in April, 1919, at the Navy Yard, New York, and commissioned in June, 1920. She and her sister ship, the *California*, were the first battleships to incorporate lessons learned from the World War pertaining to water-tight integrity. A slight digression here to illustrate these lessons as described by Admiral Taylor will not be amiss.

Although the Dogger Bank action apparently demonstrated that the lightly constructed battle cruisers of England and Germany were valuable fleet units later action in the Battle of Jutland demonstrated that these ships lacked sufficient protection. However, the battle cruisers in the latter action bore the major brunt of the fighting. Not a single vessel on either side, including the battleships, suffered a disabling casualty either from shell fire or engineering breakdown. Water in some of the engineering spaces was due to leakage from adjacent spaces and was easily controlled by the pumping plants provided. The outstanding facts of interest to the designer were the value of armor protection, necessity for the maximum number of main caliber guns, the tactical value of speed, and the futility of subjecting old ships to the attack of

modern weapons. The consensus of opinion attached increased importance to protection. In consequence the American ships building were well fitted to withstand underwater attack from torpedoes, shell fire, bombs, and mines.

Electric drive in the *Tennessee* facilitated the underwater protection demanded. The engineering plant was further adapted to fulfill the new requirements as it was much more versatile in operation and control. Fire control systems in the *Tennessee* and *California* remained as step-by-step units; but the mast structures were changed to a more massive type with the old circular fighting top and "crow's nest" vanishing. When the succeeding four vessels were building certain changes appeared desirable and selsyn control was fitted. The *Maryland,* taking cognizance of the value of aircraft assistance had a catapult fitted aft, this being a predecessor of the ones following on all battleships and cruisers. Eight sixteen-inch guns in twin turrets made up the main battery as opposed to the previous twelve fourteen-inch guns in triple mounts.

The hulls of all six ships (Battleships 43 to 48, inclusive) were similar, except for the main battery and were thoroughly subdivided for protection against underwater attack. A clipper bow marked the abandonment of the old ram bow which had persisted since the days of *Monitor* and *Merrimac* action and gave these vessels drier decks in a seaway. In addition to this radical change another was made in the fighting tops which were altered to more or less boxlike structures with small umbrella shaped tops. The cage mast was retained, though in the foremast a great portion of the height was made up of a built-up compartmented structure. (Figure 3.)

The *Tennessee, Colorado,* and *Washington* were fitted with Westinghouse electric drive propulsion units, while the *California, Maryland,* and *West Virginia* had General Electric equipment. Both manufacturers supplied similar material, the principal difference lying in the method of starting the main motors. This description for the sake of brevity will be confined to the *Maryland.* Two main turbines of Curtis design, 10 stage, and rated 11,000 kilowatts at 2065 R.P.M., and 250 pounds steam pressure each, drove individual alternating current generators rated at 13,400

KVA, 4325 volts (series generator connection), 1550 amperes, and 82 per cent power factor. The low voltage connection was used only when one generator was used to drive all four motors, an interlock being used to cut out the high voltage combination which would possibly overload the generator.

Special features which attended these installations were the inclusion of steam heating coils in the generators to preserve dryness in the windings, and blowers on both motors and generators for air cooling. Temperature coils imbedded in the motor and generator stators and connected to a special board in the control room gave means for a rapid check on condition of the equipment. Electrical and mechanical interlocks for preventing any misstep in the operation of the equipment further insured safety.

Main motors having a nominal rating of 7000 horsepower each at 170 R.P.M. were connected to individual propellers through Kingsbury thrust bearings. All motors were of the induction type starting on a built-in high resistance winding on the General Electric ships and having an external resistance on the Westinghouse ships, shifting to a low resistance winding when at operating speed. The motors were wound for 72 poles but through terminal connections were capable of being operated at 36 or 24 poles on three phase current.

Assuming a steady state condition on one of the pole combinations any small changes in speed were made by varying the speed of the main alternators and hence the frequency. Any change in frequency was immediately reflected in the main motor speed. Control of all main drive features was centralized in a single compartment or control room located abaft the after machinery space and forward of the motor rooms. (Figure 4.) By means of a hydraulic transmission from the main control board the governors and throttles of each of the main turbines could be adjusted for any demand. Excitation of the main generators was furnished by three 300 Kw., direct current generators in each machinery space, two exciters being condensing, one non-condensing. Switches on the main control board permitted of changing the excitation as the load varied and an additional control was furnished by means of a booster motor generator also manipulated from the control board. Major changes in speed were made through three pole oil-

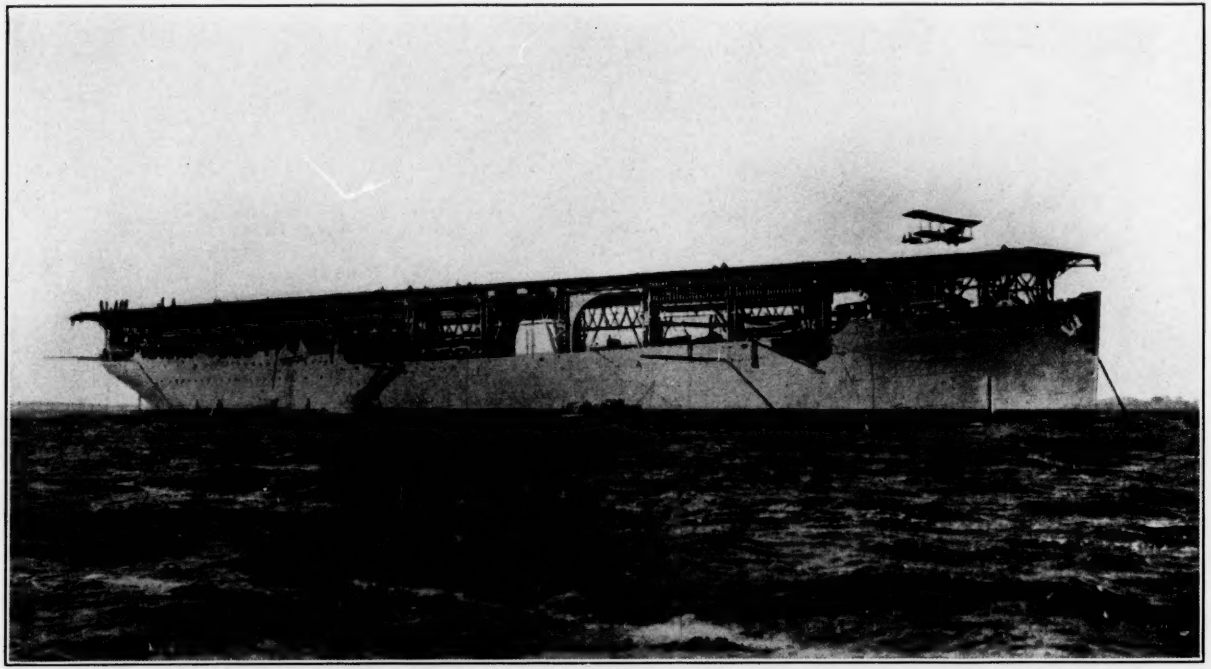
immersed switches for changing motor pole connections. Reversing the propellers consisted merely in reversing one set of leads in the three-phase motor supply. To show the condition of all circuits electric meters served to indicate the instantaneous circuit conditions. All cables were heavily insulated with varnished cambric and all exposed electrical parts were located in heavily grilled and screened cells.

Certain other features of the machinery of these latter battleships were worthy of note. The arrangement of the machinery placed the main turbo-generators on an upper machinery flat which enabled the turbines to exhaust directly downward into the main condensers, an entirely new innovation. In addition, some of these ships had condensers of a new Lovekin design while others were designed by the Bureau of Engineering. A larger number of electrical driven pumps and auxiliaries than usual were fitted also. The evaporators of the *Tennessee* marked a return to the low pressure type which for several years had been abandoned in the Navy. Operating under a vacuum and thoroughly redesigned they give new economies which redeemed their past deficiencies.

However, as a result of the Washington Treaty, a definite limit had been placed on the United States Fleet. To stay within this maximum limit certain ships were marked for disposal among them being the *Washington,* battleships 49 to 54, and the six 180,000 horsepower battle cruisers. The Treaty provided for the breaking up of these ships by certain definite dates. A saving clause, previously mentioned in this article, permitted the retention of two battle cruisers providing they were converted into aircraft carriers. For this, the *Lexington,* building at the Fore River Shipbuilding Corporation, and the *Saratoga,* building at the New York Shipbuilding Company, were selected. As practically all of the ships so far mentioned were built on a cost plus fixed percentage fee (10 per cent), cancellation of contracts was not unduly difficult, nor was the matter of conversion, though the latter did delay the delivery of the carriers by a period of three or more years.

Before continuing with the history of these latter two ships, a description of our first aircraft carrier should be given. Advocated by the General Board as early as 1915, no action was taken until

MAIN A. C. CONTROL BOARD. PROPULSION CONTROL EQUIPMENT U. S. S. "MARYLAND" AND U. S. S. "WEST VIRGINIA."
FIGURE 4.



U. S. S. "LANGLEY"—OUR NAVY'S FIRST AIRCRAFT CARRIER.
FIGURE 5.

several naval aviators, as a result of the war, recommended and forced the decision to build a "floating landing field." Under Congressional authorization in July, 1919, the collier *Jupiter* was taken as best suited to the purpose and altered to become an experimental carrier. Renamed *Langley* after the distinguished Professor Samuel Pierpont Langley, a pioneer in aeronautics, she was commissioned in March, 1922, and presented an entirely new type of vessel to the Fleet. (Figure 5.)

Most striking feature of her appearance was the addition of a huge wooden "flying" deck which covered the ship nearly from stem to stern with an area 65 feet wide by 523 long. This deck fitted with palisades for reducing wind velocities in certain deck areas, life nets for protection of "ground" personnel, catapults for launching seaplanes, elevators for hoisting planes from the hangar deck below, gasoline piping for fueling planes and certain arresting gear formed the nucleus of the carrier's facilities. In the engineering plant improvements were made such as a new low-pressure evaporating plant and a six-ton ice machine was installed. Three larger generators of 200 Kw. capacity were added in a coal bunker to supplement the two 35 Kw. exciters. The regular Scotch boilers were retained but converted to oil burning with a Howden closed ash pit system to supply air. The most noticeable engineering change was made in the stack structure with the uptakes and smokepipes being led off to the sides of the ship, control dampers being arranged so that either one of the smokepipes could be used. An experimental spray fitted to the starboard stack was intended to cool the gases of combustion and so partially eliminate the effect of the warm rising gases flowing over the flying deck.

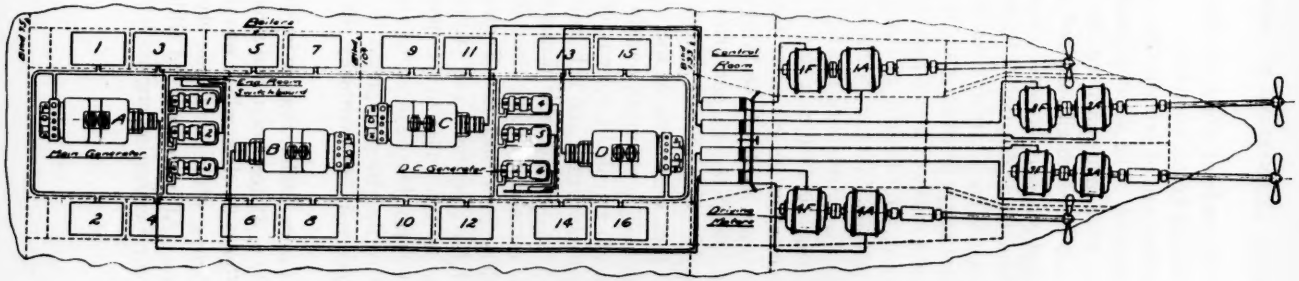
The experiments on the *Langley* dictated the majority of changes to be made to the *Lexington* and *Saratoga,* the *Lexington* eventually beginning her trials in October, 1927. These trials undertaken at first with disconnected screws, were begun under some apprehension as the machinery had lain idle for several years. Careful preliminary tests were made on all equipment, particularly the electrical installation, tc discover any deterioration. This preliminary period also was very advantageous in training the prospective operating personnel.

U. S. S. "LANGLEY"—OUR NAVY'S FIRST AIRCRAFT CARRIER.
FIGURE 5.

Although the *Lexington* (to which this description is confined) was an entirely new type to the Navy, its description here must be meager. Her length of 888 feet overall, maximum breadth of 106 feet, and depth of 74 feet 3 inches from the keel to the flying deck made her the largest ship in any navy. In addition to this was the large area of an island structure on the starboard side which included four smokepipes enclosed as a single unit 79 feet above the flying deck and approximately 110 feet long. She carried an armament of eight 8-inch guns disposed in four twin mounts and a number of antiaircraft guns in bow and quarter locations. A total of 1899 officers and enlisted men comprised the designed complement.

Although the propulsion of the ship was by means of electric drive, a difference existed between this installation and that of the previous battelship installations, partly due to the 180,000 designed horsepower fitted into the hull. Four main turbo-generators, each in a separate machinery space, furnished the power for driving the main motors. As in the battleships, the boilers lay in individual cells outboard of the machinery spaces, in this case sixteen boilers. (Figure 6.) The turbines were built by the General Electric Company and were rated at 32,500 Kw. at 1755 R.P.M. with 265 pounds per square inch steam at the throttle and 50 degress of superheat. Being General Electric turbines, they were of Curtis impulse type and comprised 13 stages. Directly connected to the turbines were the main alternators rated at 40,000 KVA, 3 phase, 5000 volts. Excitation for the four-pole field was furnished from the six-geared turbine ship's service generators rated at 750 Kw. and 240 volts, located in two pump rooms between the machinery spaces.

Driving the propellers were eight induction motors of 22,500 horsepower each, connected two in tandem to the shafts. These motors were wound three phase for 22 or 44 pole combinations and were fitted with two fans per motor for ventilation. Large water-cooled air coolers were also fitted into the ventilation system, the motor rooms furnishing part of the circulating system. Booster motor generators were used to vary the excitation for the turbo alternators. In general, the control of speed was similar to that of the battleships. Indicative of the trend of design most of the grat-



ARRANGEMENT OF MAIN PROPULSION MACHINERY

U. S. S. "LEXINGTON."

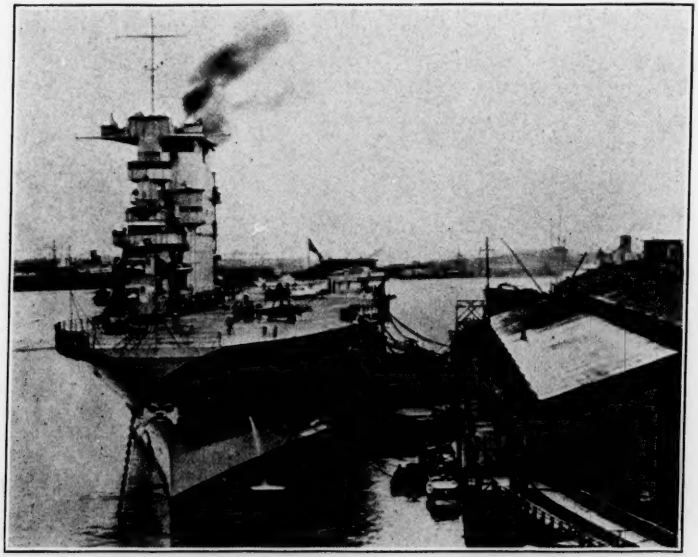
FIGURE 6.

ings and access ladders were made of aluminum alloy, and aluminum paint was used for coating heated surfaces.

These two aircraft carriers gained international renown when their trial results were published. The *Saratoga* made 33.42 knots and the *Lexington* made a 2228-mile run from San Pedro, California, to Honolulu in 1928 in which all sustained speed records formerly held by the *Mauretania* were broken. An average speed of 30.7 knots was maintained for a period of 72 hours and 34 minutes. To cap this performance the *Lexington* was impressed into service as a portable central steam generating station (Figure 7). This situation developed as a result of a prolonged drought which left the hydroelectric reservoirs for the city of Tacoma, Washington, dry. A total of 4,250,960 kilowatt hours of energy was delivered to the city from the *Lexington's* main generators from December 17, 1929, to January 16, 1930, at a cost of $78,509.60.

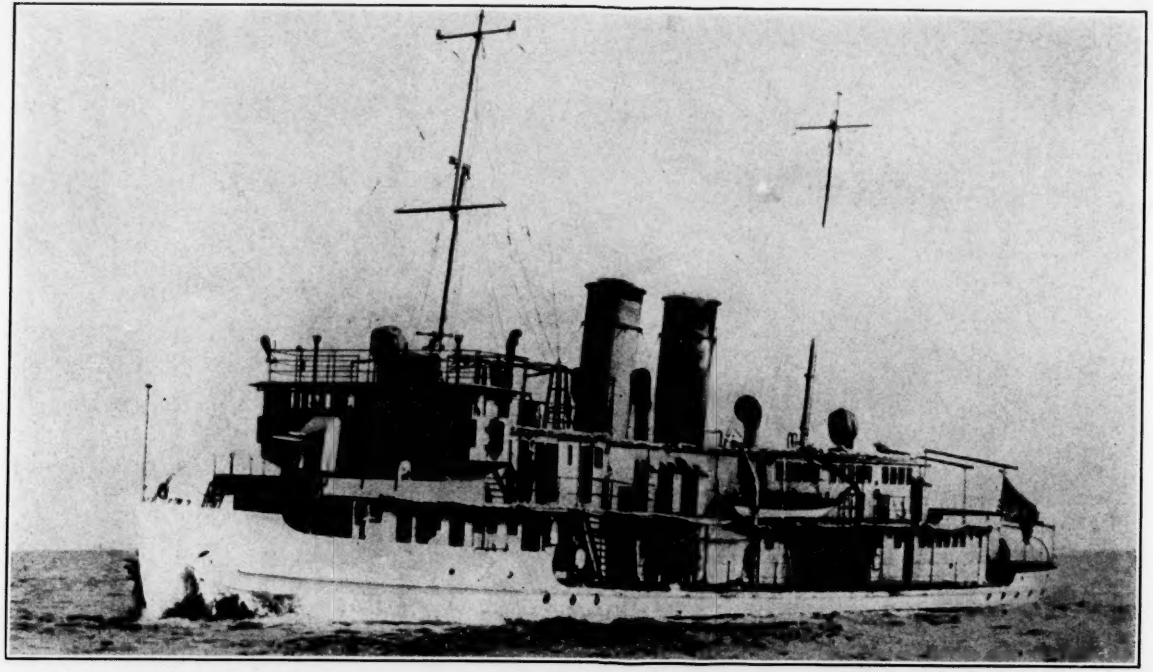
Two other series of combatant vessels other than submarines were begun. One was a direct result of the Washington Treaty and took form in the 10,000-ton 8-inch gun cruisers, the other being small river gunboats for use in Chinese waters. These latter were quite interesting, as they were some of the few vessels the United States actually had built in a foreign country. A study of the lines of the vessel would reveal the reason for this step, as the low freeboard, high superstructure, and light construction precluded their operation for any considerable distance in the open sea. Although contracts for six of these river gunboats were signed in 1926 with the Kiangnan Dock and Engineering Works at Shanghai, China, steel for their hulls was procured from the United States as required by law. Due to the interference of a revolution in China and the manufacture of engines and machinery in the United States for further trans-shipment to the Orient, a considerable delay was incurred, but eventually the vessels were built and delivered.

In general, the six ships were similar, ranging in length from 159 feet to 210 feet overall, 27 to 31 feet beam, and a maximum draft of 6 feet. The *Guam* (Figure 8) class, which was the smallest of the group, displaced 387 tons, while the *Luzon* class, which was largest, displaced 615 tons. All were powered with twin screws driven by three-cylinder triple-expansion engines later modernized



U. S. S. "LEXINGTON" BREASTED OUT BY BARGES TO OBTAIN PROPER DEPTH OF WATER FOR MAIN CIRCULATING PUMPS, BAKER DOCK, TAKOMA, WASHINGTON. DECEMBER, 1929.

FIGURE 7.



U. S. S. "GUAM"—THE FIRST OF OUR SIX NEW CHINA RIVER GUNBOATS.
FIGURE 8.

to overhung geared turbines. The *Guam* class had one closed fireroom, while the others had two firerooms. Boilers were fitted for burning oil fuel and designed to furnish steam for a sustained speed of sixteen knots, but on trials a speed of eighteen knots was exceeded. For port use a Ray Rotary oil burner was fitted on each boiler. These burners, which were individually driven, permitted the ship to operate with an open fireroom and to secure most of the auxiliaries.

In addition to the shallow draft and unusual engineering plant the hulls were equipped with multiple propellers for rapid maneuvering. The living quarters for both officers and crew were large and comfortable. Two 3-inch, 50-caliber anti-aircraft guns fitted with bullet-proof shields and several groups of machine gun mounts comprised the armament. These vessels, fitted and equipped as they were, served faithfully during troublous Chinese periods of unrest. One, the *Panay,* has since been destroyed under rather adverse circumstances.

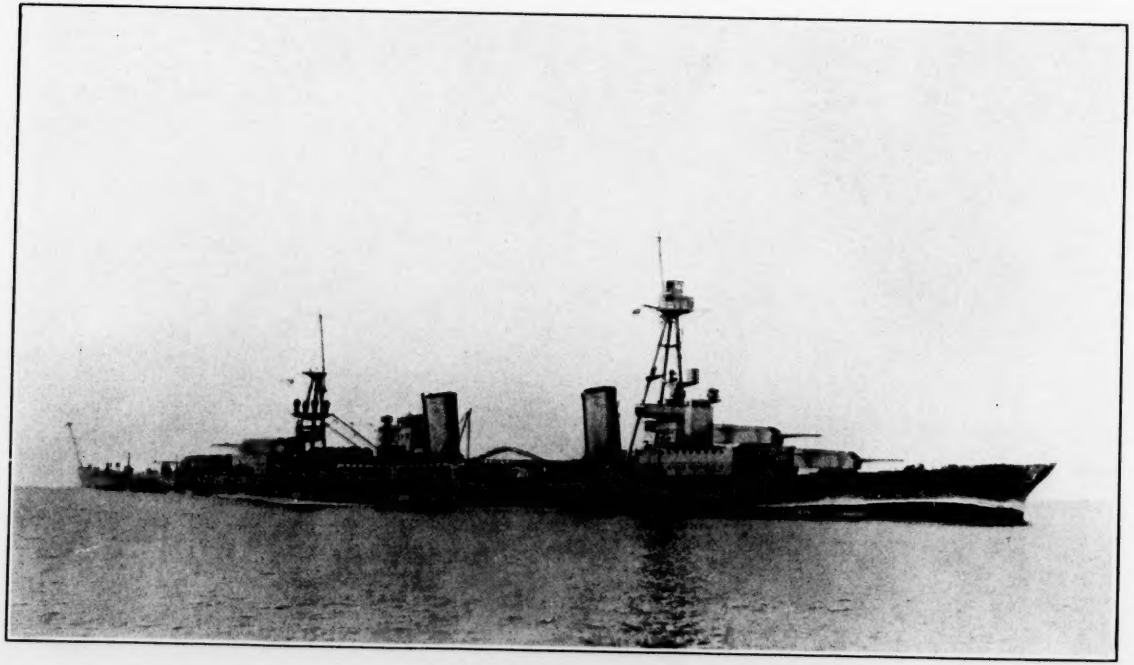
U. S. S. "GUAM"—THE FIRST OF OUR SIX NEW CHINA RIVER GUNBOATS.
FIGURE 8.

However, the vessels that have just been described, except the altered *Lexington* and *Saratoga,* are carry-overs from the World War and form no distinctive class which may be termed, as the evolutionist would say, "a mutation." The 10,000-ton cruisers did come under that category and were a direct result of the lack of limitation in vessels of that size. Eight vessels were authorized in an act approved in December, 1924, and a contract for construction of the *Salt Lake City* was concluded in July, 1926, with the old firm of William Cramp and Sons Ship and Engine Building Company. After preliminary plans and a considerable amount of material had been gathered together, the contractor was forced by economic circumstances to forfeit his contract. This was taken over by the American Brown Boveri Company, which also took over the machinery contract for the *Pensacola.* A central drafting agency operating under the name of the Marine Engineering Corporation was formed in 1929 to prepare plans for all 10,000-ton cruisers building at private shipyards at that time. Plans for the two government-built ships, the *Louisville* and *Chicago,* were also furnished by this same designer, but because of government regulations covering the purchase of materials, the plans necessarily had to be adapted and modified for navy yard construction, a procedure which is still followed.

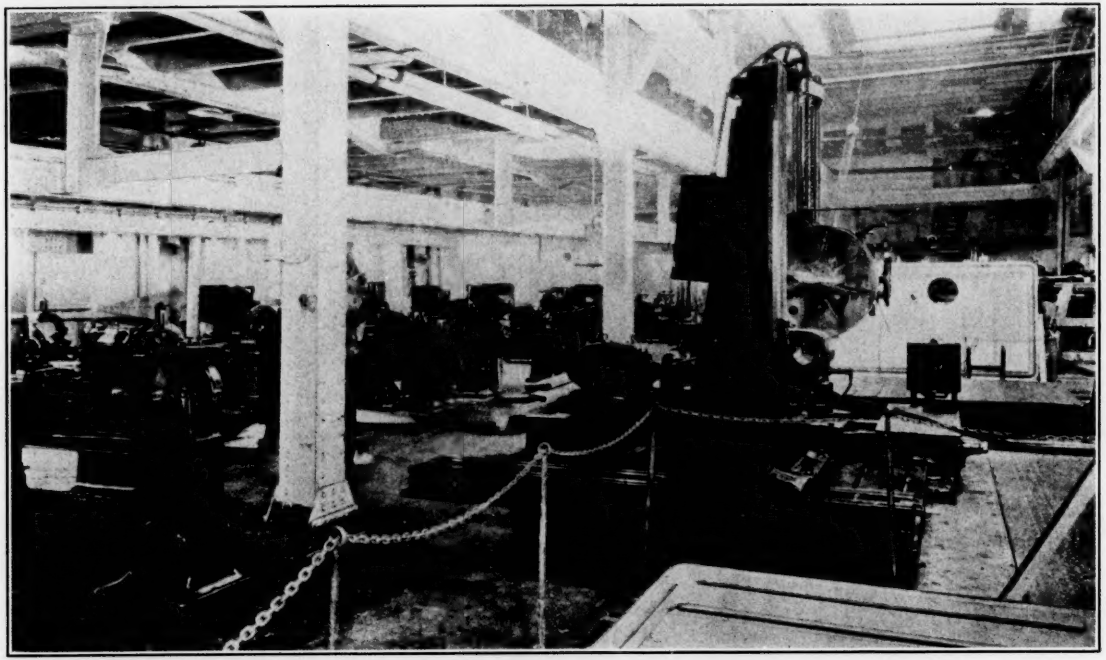
Machinery for these cruisers was designed with interchangeability one of the primary considerations, though in general arrangement there was some difference. The *Salt Lake City* (Figure 9) and *Pensacola,* first of the 10,000 ton ships, were built with two firerooms each containing four Babcock and Wilcox White-Forster oil burning boilers (Figure 10) arranged two abreast and back to back. The following six had four firerooms of two boilers each. In general the ships resembled each other in other characteristics such as overall length of 585 feet 8 inches, extreme beam of 65 feet 3 inches, draft of 19 feet 6½ inches, and speed of 32 knots. Their silhoutte was a radical departure from the "over grown destroyer" appearance of the earlier 7500 cruisers, resembling more nearly that of a battleship with their larger enclosed gun mounts, two tripod masts, two smokepipes, and flush deck. This comparison was accentuated by the modified clipper bow.

Four sets of main engines connected to as many propellers furnished power for propulsion, each unit being designed to develop continuously 26,750 shaft horsepower though 110,254 shaft horsepower was developed on the trial of one. A high and low pressure turbine were fitted with a cruising turbine coupled through a Metten hydraulic clutch and a single reduction gear to the high pressure turbine shaft. The high and low pressure turbines in turn were connected to the main shaft through a single reduction gear. A large proportion of the auxiliaries were electrically driven, though we find somewhat of a return to the Victorian era when one notes that the main air pump, lubricating oil pump, turbine drain pump, and the make-up feed pump were directly driven from the main cruising turbine. In addition electric hydraulic steering rather similar to that on the last five battleships was built into the ship.

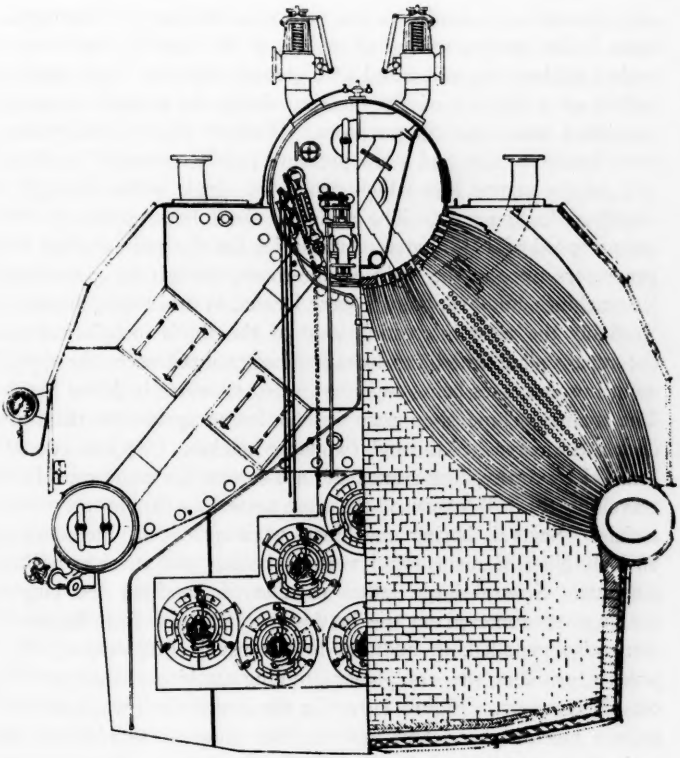
A group of ships that has been neglected in this discussion but that merits considerable attention is the ships of the train. Early during this fourth period several took their place in the Fleet under authorizations of Congress made during the wartime period. The majority were of a similar design as to hull lines, displacement and machinery installation though their internal arrangements were adapted to the prospective service for which they were intended. In this category of similarity may be placed the destroyer tenders



U. S. S. "Salt Lake City."
Figure 9.



U. S. S. "MEDUSA"—MAIN MACHINE SHOP, PORT SIDE, LOOKING FORWARD.
FIGURE 11.



B. & W. White Forster Boiler.
Figure 10.

Melville, Dobbin, and *Whitney,* the hospital ship *Relief,* and the repair ship *Medusa.* Somewhat different was the submarine tender *Holland* commissioned at the Navy Yard, Puget Sound, in June, 1926.

An examination of the foregoing ships will disclose that the *Medusa* is an entirely new type and can be compared only to the *Vulcan,* a converted merchantman which saw a short but valuable service as a repairship during the Spanish-American War. When the *Medusa* was laid down the intention was to develop a repair-

U. S. S. "Medusa"—Main Machine Shop, Port Side, Looking Forward.
Figure 11.

ship for use as a tender to the battleship divisions. The engine room is the same as that of all vessels of the class in that it was a typical oil burning unit fitted with geared turbines. Two express boilers of a Bureau of Engineering design in a single fireroom furnished steam for all purposes. Directly abaft the firerooms were located a high and a low pressure turbine arranged on either side of the center line which drove the single screw through a double reduction gear. The designed shaft horsepower of 7000 gave a speed of 17½ knots. Auxiliaries for the main engines and generators were in the main engine-room; though the generators, ice machines, and evaporators were located in other compartments. Probably the most interesting item of the ship's installation was the repair plant fitted for handling heavy machinery, the equipment in some cases being superior to that provided in Navy Yards. The main machine shop occupied 33 frame spaces on the third deck and was reached through two large hatches. Two 2-ton double beam electric travelling cranes and a 3-ton bridge crane capable of travelling the full length of the shop served to handle heavy materials. Several boring machines were provided, including a 73-inch Niles Bement Pond vertical boring and turning milling machine. Several large lathes capable of handling the largest forgings encountered on the battleships (up to 6 feet diameter) were also installed, in addition to the usual equipment of drill presses, grinders, shapers, planers, milling machines, arbor presses, cut-off saws, etc., (Figure 11). On the second deck was located a gallery machine shop and tool machine shop to supplement the main shop. Additional shops were also fitted to the ship, the large optical repair shop on the forecastle deck being an example. Two small enclosed spaces in the after end of this shop served as a laboratory and a gyro repair shop. On the third deck abaft of the machine shop was located the foundry with its 32-inch cupola capable of melting 4 tons of iron per hour, and an 18-inch cupola with 1½ tons capacity. Core ovens, grinding wheels, chipping benches, tumbling barrels, weighing scales, 4 oil-fired tilting crucible furnaces for melting non-ferrous metals, molding tubs, blowers, and travelling cranes gave a well-equipped foundry. Pattern and joiner shops, blacksmith and boiler shops, sheet metal and plating shops, pipe and copper shops, a printing shop, and an electric shop

completed the ensemble. One marked difference between the *Vulcan* and *Medusa* lay in the operating personnel. Where the *Vulcan* shops were operated by civilian personnel expressly hired for work aboard, the *Medusa* forces were all enlisted navy personnel liable to the same regulations as the men on combatant vessels.

Not until the signing of the Washington Treaty did a change in our submarines take place, which was several years after the larger and earlier German boats. Certain of these early German boats had made trips as freighters across the Atlantic and after the entry of the United States, delivered attacks against vessels in American waters. Up to the time of the armistice 437 submarines had been built in Germany and as a result of their extended operations were recognized clearly as a distinct type of weapon. Foreign countries changed their designs, the French abandoning steam driven submarines in 1920. Another recognition of the submarine was accorded in the development of a German floating dock for testing these vessels. This floating dock, constructed in Germany, was turned over to the British in 1919 under terms of the Armistice. Other nations built peculiarly hulled vessels as mother ships for submarines, some ships including wells for submarine transport. In all, considerable attention was paid to the undersea boat.

The year 1921 found the "S" type submarines completing and for many years these forming the backbone of the United States submarine fleet. A few submarines of the "T" type were built but due to limitations of their design were evidently not a successful class for no more were built. Because of capital ship limitation with none on smaller ships, all nations that could, began building larger submarines, particularly of the cruiser type. First of the new submarines were the *Barracuda* (Figure 12), *Bass,* and *Bonita,* a return to the naming of these ships with names of aquatic animals instead of the letter and number designation so long observed. A mine laying submarine, the *Argonaut,* also appeared on the register. Suffice to say their 300-foot length and 2164-ton displacement marked them as giants, the description applying equally to their main engines. As a result of the submarine construction campaign, the United States found itself in a much improved position in regard to building its own Diesel engines.

To the list of ships attributed to the Washington Treaty must be added the effect on battleship modernization. The 3000 ton defense feature of the Treaty was impressed into service; and all except five of the battleships were taken into navy yards for modernization. Because of the additional protection necessary against underwater attack, a considerable period of work was required on each ship. While the blisters were being added to the ships together with additional deck armor, the Navy Department took advantage of this delay to furnish new machinery of increased horsepower in all cases to compensate for the additional drag of the blisters. Other changes were made also, such as raising certain guns to higher elevations on the ships, improvement of the fire control system, installation of new aircraft batteries, and, in all cases, new boilers. A picture of the modernized *Texas* (Figure 13) shows the radical changes made to her general internal appearance. In fact, her first appearance with the Fleet after modernization gained for her the appellation "sport model battleship."

Other nations, interested and participating members of the Washington Treaty, found themselves in much the same situation as the United States in the years 1921 to 1923; though again there were certain exceptions and new types of vessels building. For example: the Italians were building destroyer flotilla leaders of 1900 to 2200 tons; and the British built the 11,000-ton aircraft carrier *Hermes,* and converted the old monitor *Humber* into a crane ship of 50 tons capacity much as the United States converted the old battleship *Kearsarge* into a 250-ton seagoing craneship, by adding blisters and a self-contained power plant for the crane. In this way certain vessels were saved from the scrap pile, but only through rendering their teeth impotent and converting them into more prosaic creatures. As a direct result of the Treaty, the British built a 33-knot cruiser, the *Emerald,* the Japanese in 1925 launched the carrier *Akagi,* a converted battle cruiser, and began to increase the armament of all their ships, the 7100-ton cruiser *Kako* being scheduled to carry six 8-inch guns with a 1500-pound broadside, and several three-inch guns. At the same time the Italians reached out for high speed by placing 150,000 horsepower in each of their 10,000-ton cruisers.

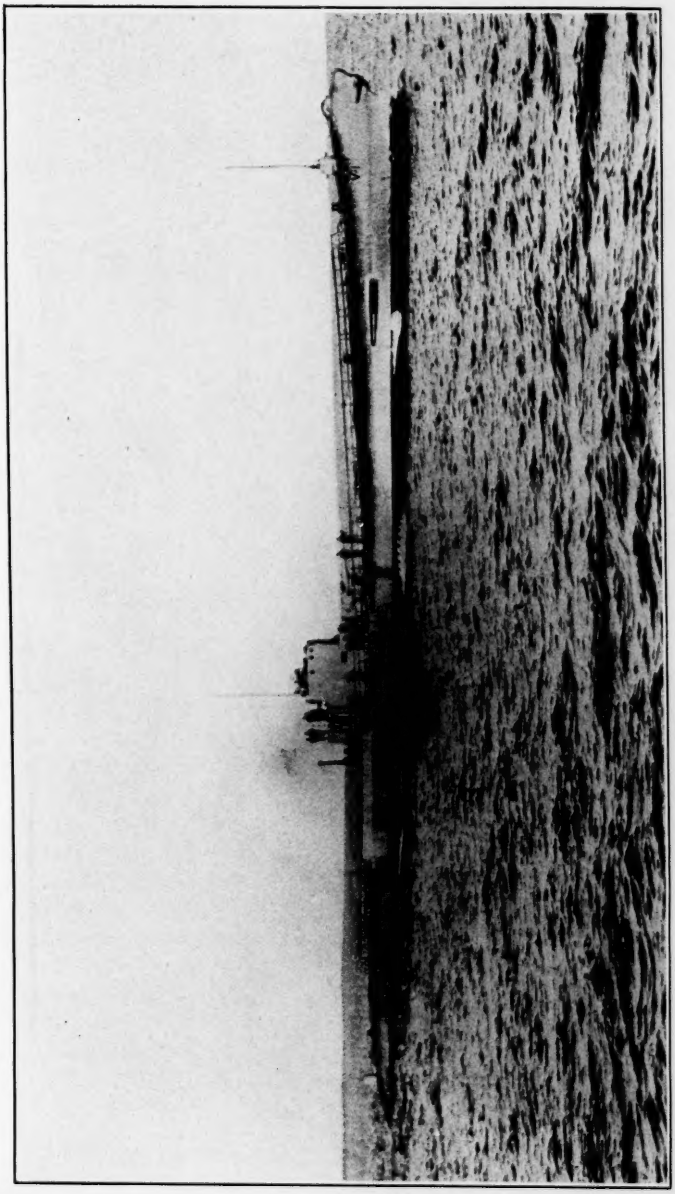
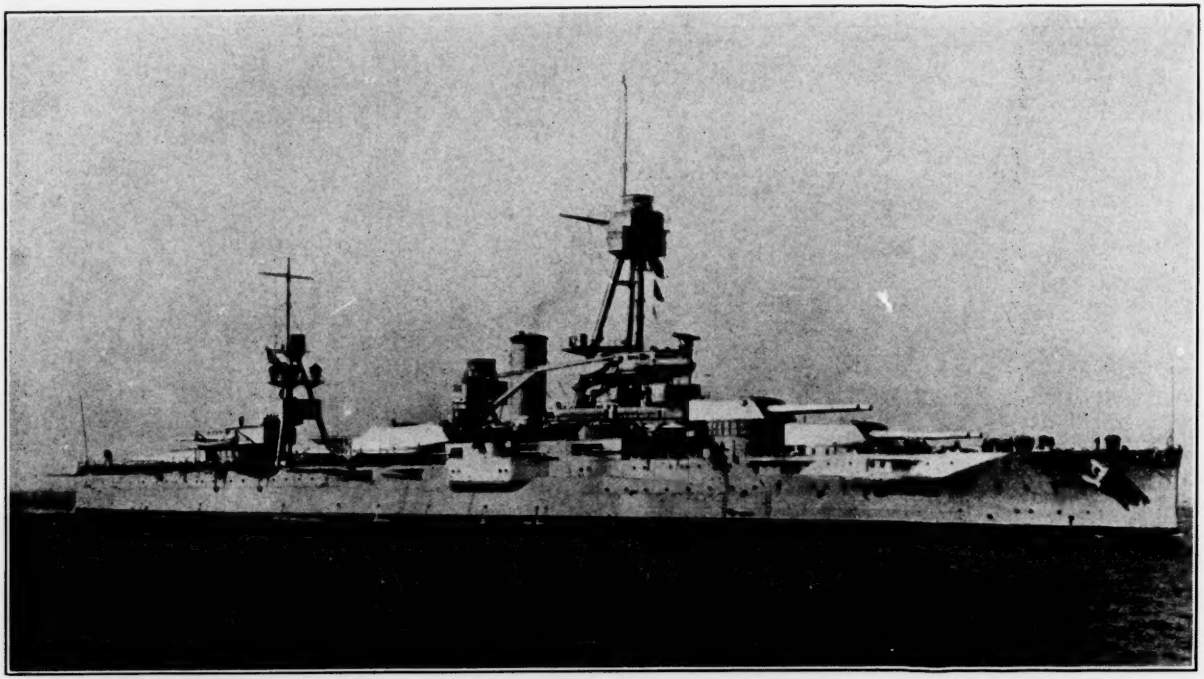
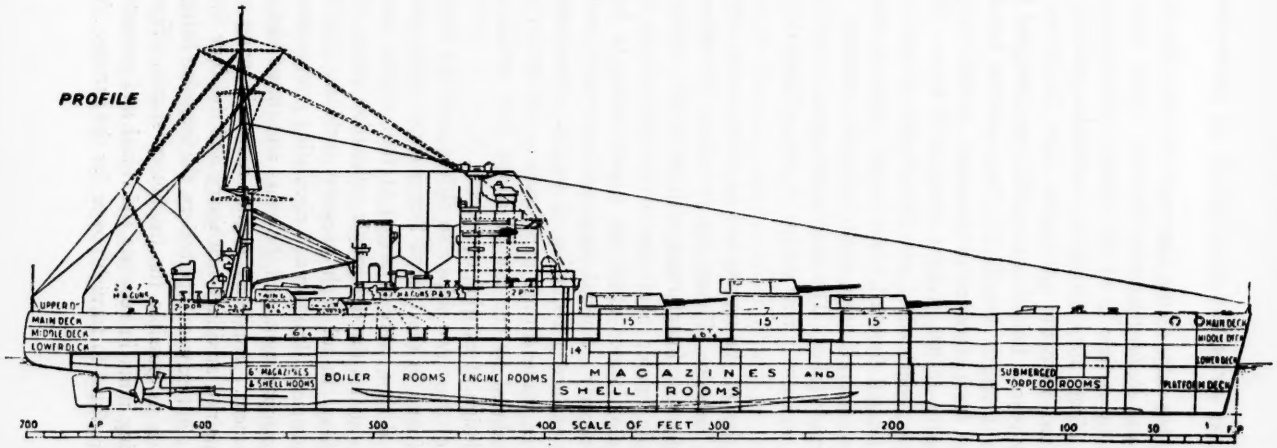


FIGURE 12.



THE MODERNIZED "TEXAS."
FIGURE 13.

THE MODERNIZED "TEXAS."
FIGURE 13.



H. M. BATTLESHIPS "NELSON" AND "RODNEY."
FIGURE 14.

Outstanding big ships of the time were the two British battleships *Nelson* and *Rodney* launched in 1925, whose construction was permitted by Article II of the Treaty. Supplementing the battle cruiser *Hood,* they formed a formidable addition to the British Fleet and were the last capital ships laid down in any navy for many years. Laid down in 1923, their designed features were as follows: length overall, 710 feet; extreme breadth, 106 feet; draft, 30 feet; standard displacement, 35,000 tons, horsepower on 2 shafts, 45,000, giving a speed of 23 knots. Their approved armament consisted of nine 16-inch guns disposed in three triple turrets located forward, twelve 6-inch guns in six turrets, six 4.7-inch anti-aircraft guns, eight 2-pounder pompons, and two submerged torpedo tubes. The sixteen-inch guns being new to the British Navy, an entirely new design of gun and mount had to be evolved.

The disposition of the turrets had its effect on the interior arrangement of the ships (Figure 14) as well as the outboard profile. To avoid smoke interference with the bridge controls which were necessarily located abaft the mid-section of the ship, the boilers were also located abaft the engine rooms to locate the smoke pipe properly. Special high tensile strength steel in the hull structure enabled a reduction of weight. Aluminum found extensive use in minor fittings and lockers. Wherever possible, weight was reduced by the use of alloys, high tensile strength steels, and redesign of existing equipment.

Machinery of these two ships also differs from the conventional arrangement found in the United States ships. The turbines of Brown-Curtis design, were arranged in four engine rooms, and drove the two shafts through single reducution gears. Cruising stages were fitted in all high pressure turbines. All turbines with their condensers, throttles and circulating pumps were placed in a forward compartment, and the gears and thrust blocks in the after compartment. Auxiliary engine rooms in wing compartments aft contained auxiliary machinery and the four fire rooms contained the eight express type boilers, the intention being to subdivide as much as possible the machinery spaces. Special hydraulic pumping units in separate individual and protected compartments were fitted to furnish power for the turrets. As in the

sixteen-inch gun ships of the United States Navy, emergency Diesel engine units were provided to supplement the regular turbo-generator units. Much of the power (including steering) throughout the ship was furnished by hydraulic Hele-Shaw units. Large centrifugal submersible self-priming pumps were also placed in separate compartments for damage control purposes.

Two other nations may be mentioned at this point. France in 1925 began building a series of 8000-ton cruisers under her 1922 law. These were the most powerful machinery units ever built in France and the largest built there since 1914. Their 100,000 designed horsepower, furnished by four independent sets of Parson's turbines, intensified the competition between France and Italy and also disclosed that the trend of thought in those nations was toward higher speeds.

Meanwhile Germany was reawakening and in 1928 began the first of four armored vessels to replace her obsolete battleships. These vessels, limited to 10,000 tons as a result of the Versailles Treaty, were a compromise between a coast defense monitor and a heavily armored cruiser. Their six 11-inch guns and Diesel engines of high horsepower promised to make them formidable antagonists of any light battleships and more than a match for any 10,000-ton cruiser subject to the limitations of the Washington Treaty. As these were the first Diesel propelled warships of any size to be built, their construction was shrouded in secrecy though details gradually leaked out. The first one to be built, the *Deutschland,* had 8 double-acting, 2-cycle M. A. N. engines fitted, driving the propellers through a Vulcan hydraulic gear drive. The engines were collectively rated as 56,800 brake horsepower though 54,000 horsepower only was available at the propeller.

The Washington Treaty having forced a new trend in naval design through the use of alloys, high tensile steels, rearrangements, higher machinery speeds, and coordinated design, also had created an evil state of affairs through only a partial limitation of armament. Severe competition crept in and forced a convention in London in 1929 at which the original signatories appeared again to settle differences. The previous seven years had created distinct national tendencies in warcraft design, the American cruisers being noted particularly for gunpower, the French and Italian for

phenomenal speeds, while the Japanese combined both at the expense of seaworthiness. This latter conference now defined the various classes of ships from 10,000-ton cruisers downwards through destroyers and submarines, and continued the battleship building holiday through 1936. Friction was bound to develop and soon came from France and Italy who would not reconcile their differences, and from Japan who insisted upon parity with England and the United States in cruisers and lesser categories, but finally agreed to a 10-10-7 ratio. Total limits were placed on each group with escape clauses as before. Before renewal of the treaty came about in 1936 Japan served notice that she would not become a party to any renewal after the expiration date. The naval building holiday at last had come to an end though France, England, and the United States reached a gentlemen's agreement to exchange information as heretofore. A recent British arrangement with Germany scrapped the naval limitation features of the Versailles Treaty and permitted her to build in excess of the 10,000-ton limit and to a certain percentage of the British tonnage.

Other changes appeared on the scene. The Babcock and Wilcox Company brought out a sectional express boiler which was used on certain naval vessels, though shortly afterward the "A" type express boiler was again reinstated together with superheat. The British destroyer *Acheron* of 1330 tons marked the trend of the times by its 35 knot speed with 34,000 shaft horsepower. Steam at 500 pounds at 750 degrees F. was a new feature of this type of plant; although the arrangement of four turbines coupled to the shafts through the two reduction gears was similar to that on older ships. Special engine room ventilation became necessary to combat the high temperatures, while air heaters were inserted in the boiler uptakes to further economy. Coincidently, Germany fitted 1600 shaft horsepower Diesel cruising engines in the *Konigsberg* class of cruisers for use at 10-knot cruising speeds. A 65,000 shaft horsepower geared turbine unit formed the main plant.

Battleship building which had become somewhat of a lost art was scheduled for a reawakening when the French in 1932 projected a 26,500-ton battle cruiser armed with eight 13.4-inch guns in two quadruple turrets forward as an answer to the German *Deutschland*. Named the *Dunkerque*, she was to have a speed of

29½ knots at 100,000 shaft horsepower, with an overall length of 689 feet and 98.4 feet beam. The international arms race was further aggravated two years later by the *Strasbourg,* a sister ship. A cruiser carrier, the *Gotland,* took the water in Sweden late in 1933, and in the United States, the *Ranger,* the first aircraft carrier so designed in our Navy was scheduled for delivery in May, 1934.

The great portion of military shipbuilding appeared to be replacement tonnage, the United States in July, 1933, opening bids for twenty-one naval vessels, including two aircraft carriers of 20,000 tons each, one 8-inch gun cruiser, two 10,000 ton 6-inch gun cruisers, two submarines, eight 1850 ton destroyers, and six 1500 ton destroyers. At the same time the Navy Yards were assigned two submarines, ten 1500 ton destroyers, two 10,000 ton 6-inch gun cruisers, and two gunboats of a new type. A part of the funds required for this building had been made available through a special grant for the purpose of expediting employment during the current "depression." In design, fusion welded boiler drums (arc welded) had now been accepted, their first installation being in the *Minneapolis, Astoria,* and *New Orleans* in 1930. The *New Mexico* finally had been modernized, having had her turbo-electric plant replaced by geared turbines. In the new ships just mentioned 37 knots was specified for the new destroyers which were to be fitted with 5-inch 38 caliber guns and 8 torpedo tubes. A high cruising radius at economical speeds was also specified. Added to the 8 destroyers of the 1932 program, they marked the first construction of these vessels in this country since the *Pruitt* (DD347), last of the wartime program, delivered in 1921. The new submarines were now of 1300 tons displacement, cruiser submarines of 2700 tons being suspended.

Light cruisers appeared to occupy the thoughts of other nations, the British in 1935, bringing out the *Arethusa* class of 5500 tons and 32½ knots, and an armament of six 6-inch and four 4-inch guns with 6 torpedo tubes. Speeds of naval vessels increased as has been indicated, the French concluding that high speeds were necessary for combatant vessels, their 45-knot *Le Terrible* being an example. Similarly, along the line of new developments, the Germans ran trials at Kiel on their new submarines in August, 1935. Although generally small in size, only 300 tons displacement,

they were visible evidence that Germany had formally thrown off the naval shackles of the Treaty of Versailles. To add to the submarine situation, the United States began a friendly competition between the builders of lightweight, high-speed, Diesels for submarine use. At this time the Diesel engine had become popular for railroad propulsion, being found in several of the well-known "streamliners." Their lightness and reliability promised to be of advantage in these ships, particularly when coupled to the propeller through a reduction gear or some other means of speed reduction.

The year 1936 brought further warcraft construction. In the 1936 Naval Limitation Conferences, Japan, as anticipated, would give no adherence to the project. The United States because of its strategic location, again opposed the smaller size battleship limitation of 27,500 tons. No restriction was placed on the size of destroyers, and submarines were raised to a 2000 ton limit. 10,000 ton cruisers were completely out of the picture. France, in the meanwhile, went ahead with a decision to build two 35,000 ton battleships, the *France* and *Patrie,* and to modernize three battleships. The result of her severe competition with Italy for Mediterranean supremacy and her desire to keep ahead of Germany was to give France the greatest submarine flotilla in the world, the largest ship being of 2880 tons with 14 torpedo tubes and two 8-inch guns. Italy in retaliation began the building of two 35,000 ton battleships, the *Littorio* and *Vittorio Veneto* of 34 knots and nine 15-inch guns. Germany proceeded with 26,000-ton battle cruisers of 32 knots carrying nine 11-inch guns, and twelve 5.9-inch guns. These were also described as carrying heavier armor than any of the wartime battle cruisers. Regretfully, in 1937, the United States began construction of two 35,000-ton battleships as replacements for older ships and as a result of foreign competition. These were augmented by the authorization of four more similar units in 1938 with a possibility of invoking the escalator clause to boost the tonnage of subsequent ships to 45,000 standard tons.

Among other naval developments during these seventeen years much progress was noted, chiefly in the field of communications and aeronautics. Early progress in radio was held up subsequent

to the World War because of a surplus of materials which had necessarily required disposition before replacements of a more modern type could be procured in quantity. The Bureau of Steam Engineering had taken on a more modern aspect in 1919 when its name was changed to "Bureau of Engineering," and in 1922 the allotment system of granting funds to vessels afloat was instituted. Disposition of wartime materials and the resulting debris of the Washington Conference caused the Secretary of the Navy in his 1923 report to describe the Bureau of Engineering as a "super-junkman, inventor, and tutor." The engineering competition received official recognition, too, through General Order 108 of June, 1923, which set up the Division of Fleet Training in the office of the Chief of Naval Operations. Removed from the Bureau of Engineering, it now became a Departmental function, though from some of the comments received in official correspondence and those appearing in the JOURNAL, the new office had no bed of roses. Notwithstanding all this and the preparation of lengthy forms by the ship's engineer officer, competition between ships of similar types became standardized and centralized.

In the field of communications the United States was practically the outstanding leader. When in 1920 the government noticed that control of the United States commercial radio facilities was passing into the hands of a foreign corporation, the Navy Department called in representatives of the three largest radio manufacturing concerns and placed the story before them, recommending that an American company be formed to take over these properties. Of this conference the Radio Corporation of America was born. In the field of underwater communication, the sonic depth finder was first described in 1923. With this instrument deep sea sounding and sounding of the approaches to channels could be performed with ease, doing away with the laborious process of heaving the deep sea lead.

Radio broadcasting had by this time become a regular facility; trans-Atlantic telephone in 1923 was assured by actual test; and commercial wireless showed a similar growth. The establishment of transcontinental air service stimulated commercial radio, particularly in governing the airways and navigational facilities. When the ZR3 (Los Angeles) was brought to this country, piloting was

conducted by radio, though communication was somewhat bad as a result of interference. Following this came a very thorough research into the " ultra " frequencies from 100 to 20,000 kilocycles. As the frequencies from 2000 to 3000 kilocycles were reached a marked jump in range was noted. Experimental transmitters and receivers were built and installed on certain ships for further test. On board ship the older arc sets were disappearing fast and spark sets were being relegated to the emergency equipment. Vacuum tube transmitters were replacing the former units. Vacuum tubes by 1931 had reached considerable size and capacity; and photo-electric tubes had come to stay. Among the high power tubes were pliotrons and thyratrons, now becoming an industrial asset through their ability to control large powers, but tracing their beginnings back to the older three element vacuum tube of radio.

The new arm of the Navy, aviation, took concrete form in 1921 when Admiral Moffett was ordered to report to the Chief of Naval Operations for aeronautical duty and later that year became chief of the Bureau of Aeronautics which had just been formed. At this time military aviation was having growing pains for the United States was determined to rely on its own production and design. Lt. MacReady, U. S. A., had as early as 1921 made a world's record altitude flight. Aircraft carrying mail steamers had been proposed as early as 1923, and in the Navy, catapults were being fitted to the battleships at about the same time, the *Maryland's* catapult having previously been mentioned. During the war period and subsequently the Navy had designed and had built several large flying boats for patrol duty. One of the largest of these, the NC4 made history in 1919 by flying the Atlantic. However, some smaller boats, the H-16 and F5L, were built and powered with Liberty motors. Though temporarily satisfactory, improvements were possible and the PN-7 patrol boat (Figure 16) built at the Naval Aircraft Factory in Philadelphia resulted. A modification of the PN-7 made the famous Hawaiian flight shortly after. Development of aircraft was accelerated, however, when a reliable radial-air-cooled engine was assured. Although development of an engine of this type was started in 1916 by Lawrance, the first endurance test was not undertaken until 1921, and a commercial product was available in 1925 and 1926. From a technical

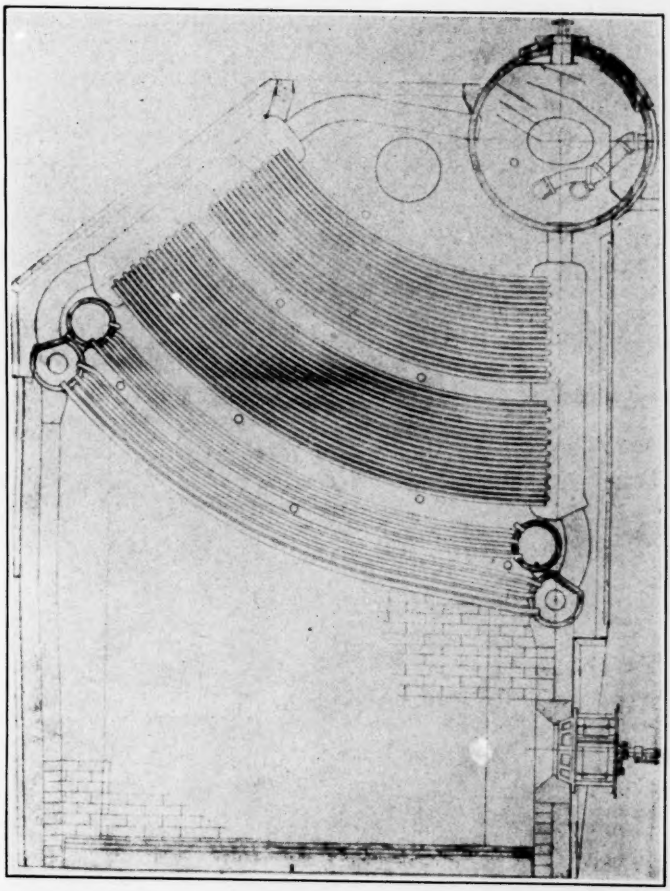
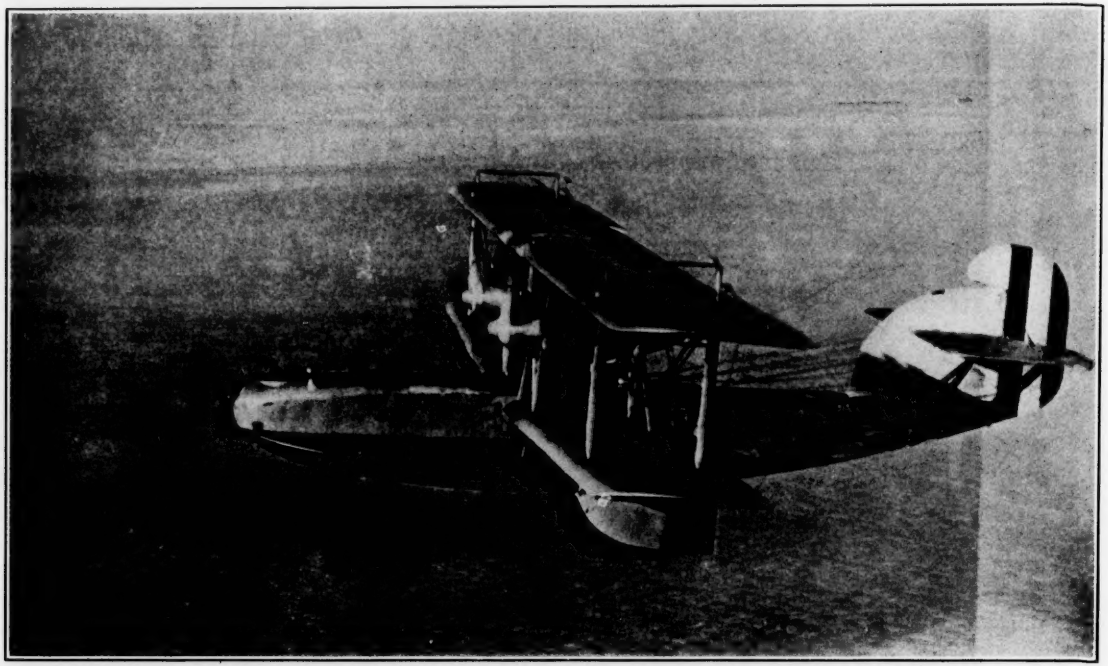


FIGURE 15.



PN-7. In Flight.
Figure 16.

viewpoint 1927 marked the supremacy of American air-cooled aircraft engines based principally on the Lawrance patents. Of course, foreign development was not lacking either, for in 1931 Junkers of Germany brought out its "*Jumo* 4" heavy oil aircraft engine. The seven and nine cylinder single new radial engines now usurped the field displacing the "V" type engines from their leadership. Further improvement in aircraft engines was made in 1932 with the appearance of the 14-cylinder Twin Wasp engine.

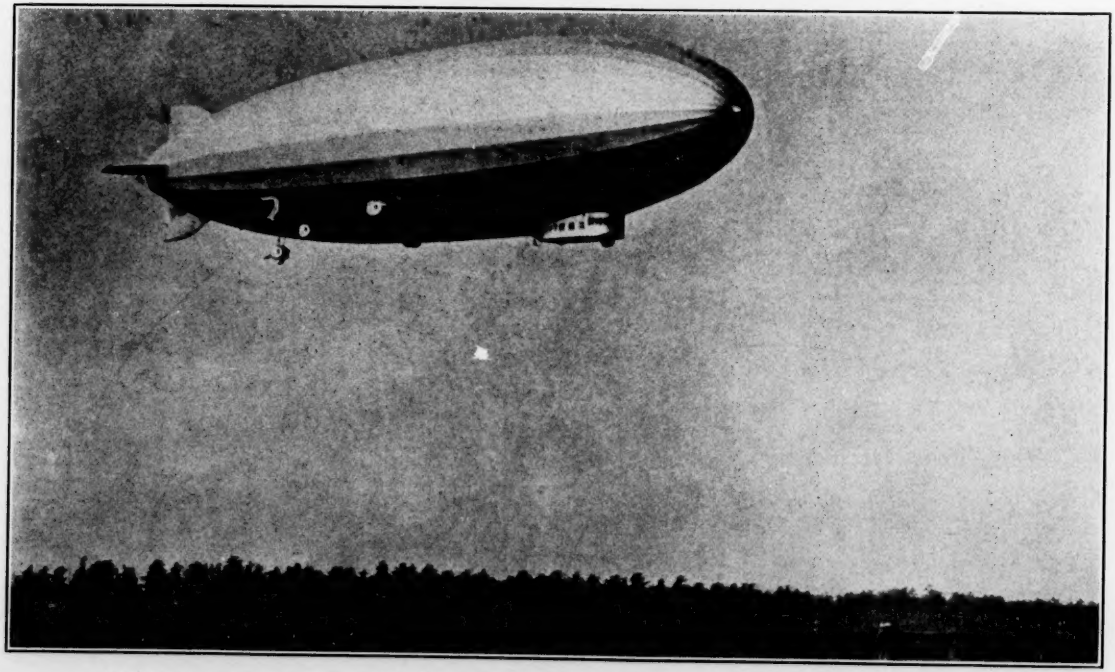
In the field of lighter-than-air, rigid airships of the Zeppelin type were most prominent. After Germany, England was the first nation to begin such construction, starting with the R-38. In these foreign airships a new construction, metal duralumin, was brought out. This metal, combining great lightness and high strength, was found superior to plain aluminum and has been used for many other purposes since. In recent years a still lighter alloy made of magnesium and given the trade name "Dowmetal" has also become available for similar uses. The Zeppelin ZR-3 (Figure 17) was transferred to the United States by Germany in 1924 and renamed the *Los Angeles*. Her shape, different from that of the *Shenandoah,* showed greater attention to aerodynamic features. The JOURNAL does not give much detail of these ships but has noted them in the interest of naval engineering. Lighter-than-air development was encouraged by the discovery of helium in certain natural gases of Texas some years before. The Bureau of Mines placed a helium recovery plant in operation at Fort Worth, Texas, in April, 1921, and with the cooperation of the Navy developed a series of tank cars for the transportation of the gas which removed the hazard of handling highly inflammable hydrogen. Meanwhile, in 1925, construction of a super-Zeppelin was planned, the design being made by Goodyear. A temporary setback to new construction along these lines was caused by the destruction in September, 1925, of the *Shenandoah* during a severe storm over Ohio where the ship had been ordered in connection with civil ceremonies. However, construction of two new air giants, the *Akron* and the *Macon,* proceeded with certain improvements as a result of the accident. One was the consolidation of the control cabin into the ship's structure instead of a suspended unit as before.

PN-7. IN FLIGHT.
FIGURE 16.

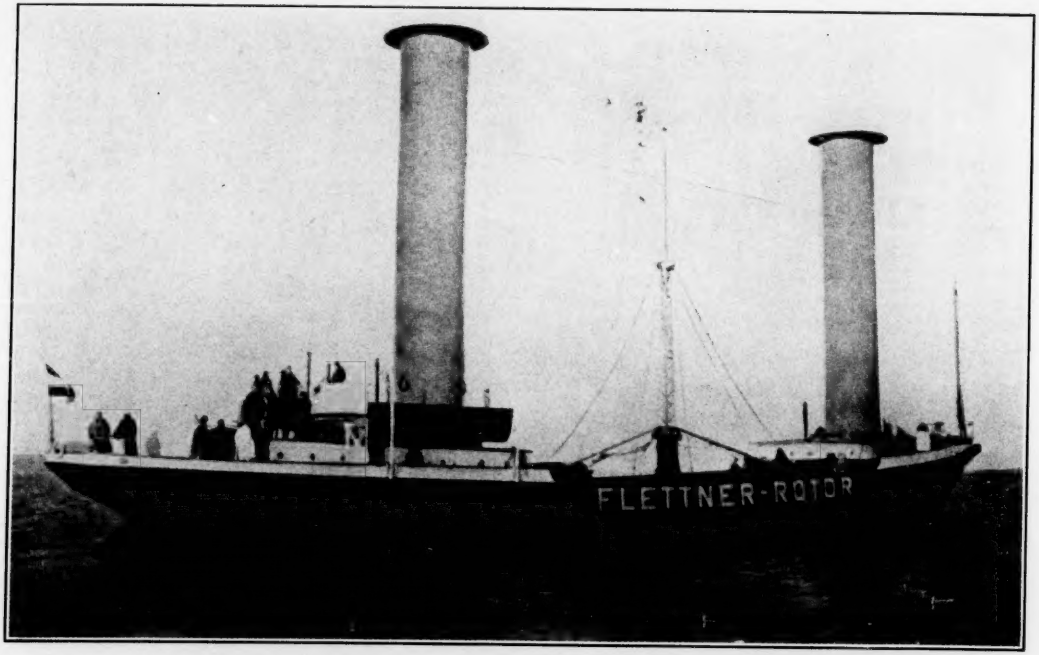
Exhaust water recovery apparatus fitted to the engines gave further means of control over buoyancy as it partly recompensed for the loss of fuel during extended operations. In the Fleet proper the *Patoka* was converted to a tender for these ships by construction of a large mooring mast in her stern structure, and the *Los Angeles* made a landing on the deck of the *Saratoga* in February, 1928. Another severe setback occurred in 1930 with the destruction of the British R-101 by fire, bringing forcibly to the attention of all the value of helium. Undaunted, the Germans proceeded with construction of the *Graf Zeppelin* and the *Hindenburg* for use in trans-Atlantic freight and passenger service with two-day crossings possible. When completed, the *Hindenburg* was the largest airship in the world. It, too, went down in flames two years later.

Other events and discoveries served to assist the advance of naval engineering progress in addition to that of ship construction only. The trend of the times in intensive invention was noticed in many fields ashore and afloat such as the tests conducted at the Engineering Experiment Station and the Naval Research Laboratory at Bellevue which had been built shortly after 1920. At the Experiment Station a series of tests were conducted in 1921 on the use of Sil-O-Cel as furnace insulation. Further tests were conducted at the Fuel Oil Testing Plant (in 1935 becoming the Navy Boiler Laboratory) at Philadelphia on Quimby screw pumps for fuel oil followed by full scale tests on the Dyson boiler. Comparisons afloat between the Kingsbury and horseshoe thrust bearings took place, primarily to ascertain friction losses, while the Falk Company tested the 22,500 horsepower gears for the *Detroit* and *Raleigh* in its plant, using the method of losses. The tests of refractories was continued at the Fuel Oil Testing Plant in addition to those tests at the Experiment Station. A similar plant at Mare Island tested soot blowers for boilers to find a replacement for the old steam and compressed air lance. The results were very surprising as the boilers were cleaned more thoroughly in twelve minutes using soot blowers than four men could accomplish with hand lances in a full day. Individual forced draft blowers were also tested at the Philadelphia plant as were Ray oil burners in 1925.

One of the greatest improvements affecting plant operation and maintenance came through the efforts of the Experiment Station



"ZR-3" Arriving at Lakehurst, N. J., October 15, 1924. Has Been Renamed "Los Angeles."
Figure 17.



THE GERMAN SCHOONER "BUCKAU," FITTED WITH FLETTNER-ROTOR TOWERS.
FIGURE 18.

when Navy Boiler Compound 1923 was released to the Service. Its use brought about cleaner boilers and feed lines together with reduced corrosion. However, although this mixture gave excellent results, certain defects in its action were noted. As the new ships were reaching out toward higher steam pressures and closed feed systems for the elimination of entrained or dissolved oxygen some new compound was necessary. Added to this was the experience gained with use of the older compound and a better knowledge of the chemistry of feed water treatment. The result was Navy Boiler Compound, 1933, which has since justified itself in service use. In some cases, service reports indicated that because of its action all scale had been removed from the boilers. Other reports stated that the rate of scale formation was reduced, priming was absent, sludges were decreasing, corrosion was much reduced and alkalinity control was good. A new boiler water testing cabinet also was issued to enable the engineer officer to maintain a closer control over the "life blood" of his installation.

The safety of life was another consideration marked for attention. To the loss of two submarines of the "S" type may be attributed the initiation of this study. Two distinct creations emerged. First, attention was directed to submarine escape methods and gave result to a "lung" worn by each man and a built-in escape lock in each submarine. Courses of study in "lung" training were given at the Navy Yard, Washington, and at the Submarine Base in New London, Connecticut; and before a man was considered qualified for submarine duty, he was required to pass the tests in the escape tanks provided for the purpose. The second creation was an underwater acetylene cutting torch for use in attacking submerged steel objects for the purpose of access or reduction. The torch has since become a commercial item.

One of the continuing tests in the Experiment Station was and has been on condenser tubes. For many years Admiralty metal had been a standard item for tubes the world over. With the advent of nickel and its alloys a new investigation followed, monel metal, nickel, copper-nickel, and corrosion resisting steel being tried with copper-nickel being adopted as one of the best.

Afloat an outstanding trial was conducted on the S.S. *Mercer* in the substitution of a pulverized fuel plant for an oil burning plant.

THE GERMAN SCHOONER "BUCKAU," FITTED WITH FLETTNER-ROTOR TOWERS.
FIGURE 18.

A successful demonstration came from this, though upon looking back a similar installation was tried by the U. S. Shipping Board on one of its vessels in 1922. In a similar fashion a Todd pulverized coal burner was tested at the Navy Fuel Oil Testing Plant in 1928 and the S.S. *West Alsek* converted.

The work of the Navy's laboratories and tests of commercial equipment carried out by them has merited the highest consideration. Certain phases of their work has had to do only with pure science, while others carried out the prosaic, non-spectacular work of routine testing. Some work was undertaken by the navy yards, but in the main it was confined to the laboratories. With the exception of the change in name of the Fuel Oil Testing Plant at Philadelphia, no other change has occurred for several years, the last alteration to the original set-up being made in 1922, when the Electrical and Mechanical Laboratories of the Navy Yard, New York, were combined into the Material Laboratory. Three principal sections, electrical, mechanical, and gyro formed the unit with a light and sound section and a battery section added to take care of the increased work load. Issuing from these sections were a considerable number of improvements in commercial products, including the underwater torch mentioned in connection with submarine rescue work. To this may be added the Navy's sound motion picture equipment in 1931, in which a definite ruggedness had been developed to overcome the delicate construction of the existing shore equipment. Improvements were made in cable, the old steel braided lead covered armor cable being abandoned because of weight characteristics and a special heat and flame resistant cable developed with an aluminum armor. The cable situation was in reality a three-cornered affair, the Bureau, the cable manufacturers, and the Materials Laboratory all cooperating to produce a satisfactory product. The change in cable construction was accelerated by the change in power on new ships, the destroyers of the 1932 program having been designed with a 250-volt, 60-cycle, three-phase system. New cables were necessary because of the higher peak voltages resulting and the peculiar inductive effects resulting from the use of alternating current. The higher voltages, particularly the later 440-volt services, brought in enclosed switches and dead front switchboards. Bakelite also found use in insulation,

replacing the earlier composition, and in connection boxes and for gauge cases, because of its lighter weight. An illustration of the reduction in weights is found in the six-inch gauge case, which in brass weighed 5 pounds 8 ounces and in bakelite weighed 2 pounds 5 ounces.

The Research Laboratory carried out its functions in a quiet, unobtrusive manner, leaning toward the more scientific achievements and cooperating closely with the Bureau of Standards. Much of its work was of a very confidential nature, covering naval communications such as radio and sound detection systems. An outstanding report of the Research Laboratory was published in a recent issue of the JOURNAL. The beginning of the report may be traced to failure of the early 10,000-ton cruiser stern castings in 1931 although some research had started in 1930. Much upset over this complication and desiring to know more of the technique of steel casting, Naval engineers made investigations of the casting industry in this country and abroad. Since much of the difficulty was traceable to improper design, the Laboratory launched its study into the results of various designs and made its report accordingly. Added assistance in the research was lent by the non-destructive testing of castings and welding afforded through radiographing or gamma ray testing with radium. Many outside manufacturers began similar analyses using X-rays instead. Welding had reached such a stage in manufacturing processes that it was now a standard method of fabrication, in some instances weldments replacing castings. Fusion welded boiler drums had been accepted for cruisers in 1930 and this step, along with non-destructive testing, contributed strongly to the acceptance of welded boiler drums by civilian authorities six months later, just ten years after most manufacturers had strongly objected to the use of welding. Creep tests of metals were also instituted to determine the characteristics of steels under elevated temperatures brought about by high steam pressures and superheat.

Returning to the Engineering Experiment Station, we find that a valuable criterion in the purchase of lubricating oil was established by means of a " work factor." Although the " work factor " method is not new to the Service, packing having been so purchased for many years, 1920 marks its formulation at the Station for use with oil, 1928 the date when it became definitely usable, and

1930 when it was first employed in the awarding of an annual contract. Essentially the method involved a complete physical and chemical analysis before and after a 100-hour run in an oil endurance testing machine. The oil showing the least depreciation during the test was accepted under contract on a "Service Cost per gallon." Here may be added a note of the change in the Navy's fuel oil specifications rewritten shortly after 1930. Forced by the increasing cost of fuel oil, the advent of "cracking" and hydrogenation of crudes for a greater gasoline yield with a smaller yield of heavier oils, and aided by the design of satisfactory fuel oil burning equipment for heavy oils, a complete revision of the specifications became necessary. The result was the replacement of Bunker "A," "B," and "C" fuel oils with one single oil of a lower grade, similar to the old Bunker "C" oil.

A few more developments of the laboratories may be cited before taking up the next phase of naval and marine engineering. Again the Experiment Station receives mention by its use of a locally developed "Arcronograph" for the electrical-magnetic inspection of welds, classification of welders, and the grading of welding electrodes. The Research Laboratory proceeded to investigate gear noises for engine rooms, making direct measurements of sound levels in decibels. Much of the characteristic of a noisy engine was found not in the noise level, but in the quality of the sound generated, together with its transmission through the hull structure.

A few important machinery changes that were made to existing units of machinery served also to take some of the sting out of maintenance. Although minor in appearance, their adoption has probably led the way to the "better life" for all. For example, the electrolytic concentration indicator first used on the *Tennessee* to show the grains per gallon of salines in solution in feed water assisted materially in maintaining a pure distillate. The first unit of this type was of the resistance type with a conductivity cell and was balanced through a Wheatstone bridge arrangement to give a direct reading on a galvanometer. Today's instrument is self-balancing and reads directly without any mystic passes to place the unit in balance. The *Maryland* had two 900-horsepower Diesels installed which were arranged to exhaust through a waste heat

boiler. Used at anchor for auxiliary electrical generation, they formed the pioneer emergency power source of this type, exempting storage batteries. Today in many merchant vessels and practically all new naval vessels, Diesel generators are the primary source of emergency power.

In civil shore practice turbo-generating stations were built with bleeder turbines. These were used principally in process industries where steam was bled at a definite pressure from a turbine stage for use in process treatments. Added to this was the practice of deaerating feed water in a closed feed system for the purpose of removing dissolved or entrained oxygen and so reducing corrosion which was aggravated by the high steam temperatures and pressures coming into general practice. A pioneer steam generator of the high-pressure type was found at our own Experiment Station at Annapolis when a 500-pound boiler was installed in 1915. In 1923 a 1200-pound B. & W. boiler was placed in a generating station of the Commonwealth Edison Company of Chicago. To meet the challenge of these higher pressures welded steam piping and Van Stone joints were necessary. One high-pressure plant followed another, and today several plants operating at 1400 to 1800 pounds are now in existence, with some European boilers, such as the Velox, being designed for operation at the critical pressure. To these boilers we may add the unusual plant built by the General Electric Company for the Hartford Electric Light Company. Engineered by W. L. R. Emmett, who is responsible for today's electric drive ship, it was in essence a double unit having a mercury boiler which supplied a mercury vapor operated turbine which in turn exhausted into a heat exchanger type of boiler to generate steam from water to operate a turbine of the usual type.

On the ships themselves rubber vulcanized to the outboard shafting replaced the time-honored bronze protecting sleeves on the *Leviathan* in 1922, followed by a similar trial on the *Denver's* replacement shafts. Rubber gaskets on the shaft taper replaced the older tallow red lead seal between the shaft and propeller. Rubber stern tube bearings, used for four years previously on pumps as standard equipment, were fitted to ships in 1922 and have found increasing use since. Much of their superiority over lignum vitae is reported as being their increased resistance against the abrasive action of sand and grit.

In Great Britain oil and water separators were fitted to ships to remove oil from bilge water and so prevent the contamination of harbors. This was a more or less legal development resulting from the British Navigable Waters Act of 1922. To serve the same purpose the French brought out oil separating barges which removed water by gravity and centrifugal separators reducing the oil content to 2 to 7 parts of oil per 100,000 of water.

For wear hardness chromium plating became universal in 1927, being adopted shortly thereafter by the Navy for plating of exposed metal surfaces. Yet this same metal alloyed in stainless steel failed miserably to protect against corrosion some years later when used in salt water pipe lines and in ship's gasoline tanks and necessitated a return to mild steel plate and lead lined pipes. Chromium bearing stainless steels were, however, used increasingly in turbine blading, as they were found to resist the erosive effects of wet or superheated steam better than the softer alloys then in use.

Only a few more of the smaller engineering changes need be mentioned from this point. Patented in Germany in 1925, crumpled aluminum foil found wide use as a heat insulation in 1932 because of its dead air spaces and superior heat reflecting qualities. Later as pressures and temperatures increased the Navy added sectional and segmental molded pipe coverings, felted mineral wools, and insulating cements to replace the 85 per cent magnesia coverings. Cone joints for high-pressure joints were adopted in 1934, only to be abandoned, and for non-ferrous pipe sweated joints were adopted. These latter were also used on the refrigerating systems which now used Freon or F-12 as a refrigerant. In the field of lighting a thorough illumination survey made in 1932 and 1933 on a selected group of naval vessels by commercial illumination engineers revealed severely unsatisfactory conditions, the lighting level being very low due to poorly located and poorly designed fixtures. A table of standard illumination values for various compartments was the outcome and all of the lighting fixtures were redesigned. A blessing to all engineers was the Wilson valve gear for reciprocating pumps. Replacing the old flat type slide valve, it banished most of the troubles of sticking valves, the general cure for which was to pound on the valve chest with a monkey wrench each time the pump stopped.

No naval engineering history can be complete without a description of the merchant marine. Some of the ships have been mentioned, such as the *Mercer* with her pulverized fuel unit, but the most striking note of this period is the large number of Diesel powered ships. Several Coast Guard cutters, such as the *Mojave,* built in 1921, had been fitted with turbo-electric synchronous motor drive of 2600 horsepower. Marine Diesels had reached 4800 brake horsepower in 1921 and the first motorship with a double-acting, two-stroke Diesel engine was projected by Blohm and Voss in Germany. In 1924, just three years later, an order for a 20,000-indicated-horsepower, 20,000-gross-ton liner was placed in England. This probably was the *Aorangi,* of 23,000 tons and 18 knots, completed in 1925. The *Challenger* had her geared turbines replaced by a 3000-I.H.P. Sun-Doxford engine that same year.

Scanning the records of the past we find the *Mauretania* still maintaining her supremacy, for in 1924 she made a crossing of the Atlantic in the record time of 5 days 3 hours and 20 minutes, an average of 25.6 knots being maintained. As an antithesis to the *Mauretania,* a very striking and unusual ship appeared in November, 1924. Designed as a sailing vessel, but with rotating cylinders instead of sails, she represented the outcome of a thorough areodynamical study (Figure 18). In the United States construction was at a low ebb in 1925, the only vessel of note being the Coast Guard cutter *Bear,* built with a direct current electric drive of 1000 horsepower for Arctic service.

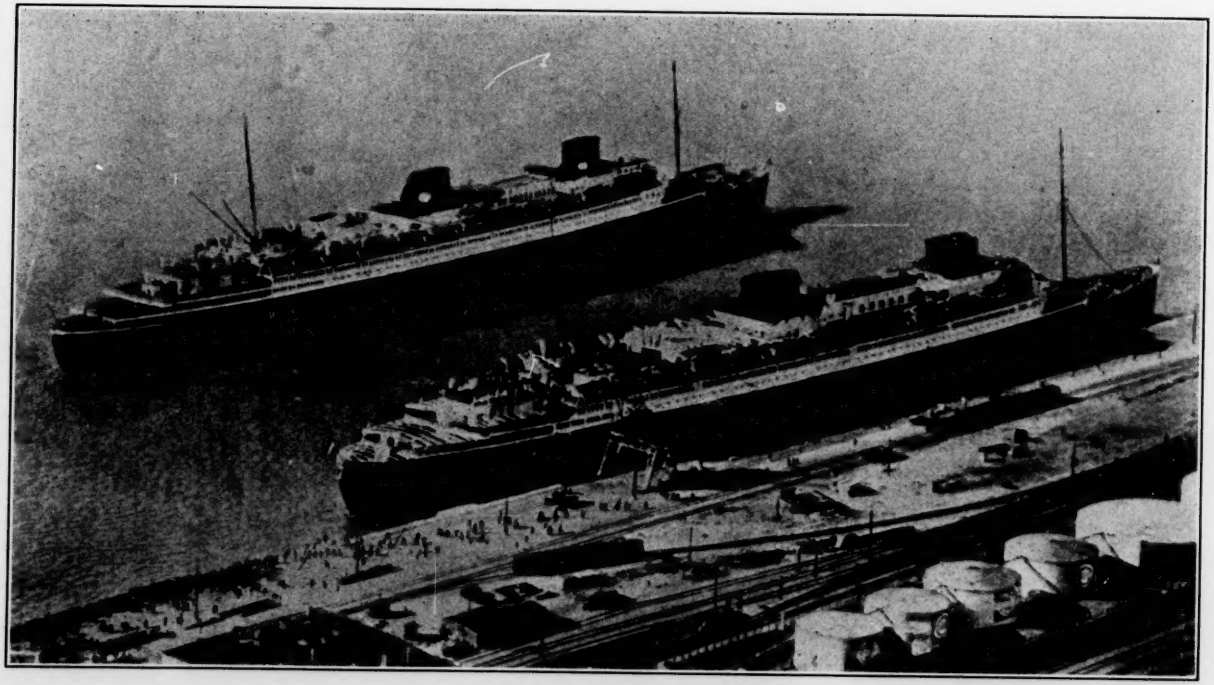
A year later the Shipping Board placed 2900-horsepower Diesels in the *Seminole.* In Scotland the *King George V* took form, her machinery being designed by Parsons for 550 pounds of steam with a single geared turbine drive. Double reduction gears were at this time unpopular, particularly in Europe, but as time passed opposition waned considerably. In Germany a combination of reciprocating engines and turbines was made on the fishing steamer *Sirius* with an economy of 25 to 30 per cent stated. The turbine in this ship was connected to the reciprocating engine through a Föttinger (Vulcan) coupling and was used only for ahead running. That same year (1927) the Germans developed a reciprocating steam engine without steam chests or receivers, the steam flow being direct through the valves from one cylinder to the next. An engine of this design was fitted to a trawler, the *Claus Bolten.*

Awakening somewhat from a dormant state, the United States now built a commercial passenger vessel of 30,250 tons for coast to coast service. Her plant of 17,000 horsepower was the first large turbo-electric plant found in any passenger ship and served to propel her at 18 knots. Two more similar ships, the *Virginia* and *Pennsylvania,* followed all with synchronous motor drive. Britain followed suit with the 19,000-ton *Viceroy of India* in 1929, while the U. S. Lighthouse Service had three Diesel electric lightships built.

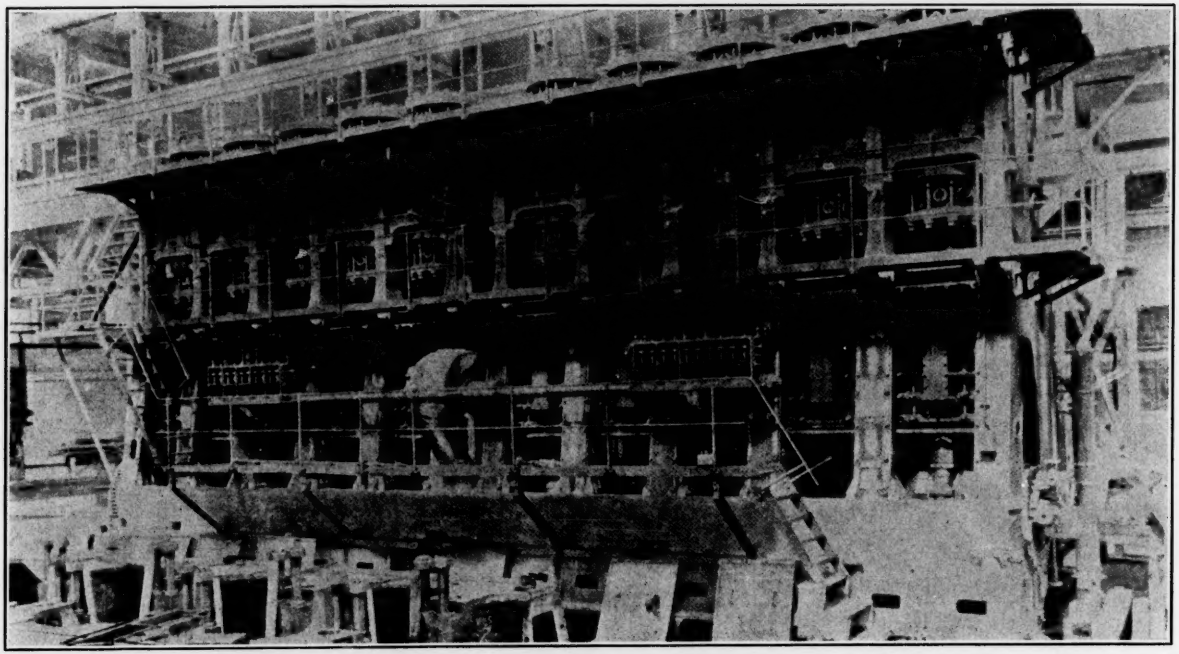
Germany, too, was showing remarkable powers of recuperation by building the turbo-gear ships *Bremen* and *Europa* (Figure 19) for trans-Atlantic service. Each ship was designed for 46,000 tons, 27 knots, and 120,000 horsepower. Four-day Atlantic crossings now appeared possible. Another ship, the *Milwaukee,* was built, using geared Diesel engines, the first so recorded. More Diesel ships followed with the English *Britannic,* of 27,000 tons and Diesels of 10,000 I.H.P. each, and the French *Lafayette,* of 25,600 tons, 16,000 to 18,000 I.H.P. delivered by engines and propelling the ship at 17½ knots (Figure 20).

Following the *Virginia,* the Dollar Lines built the *President Hoover* (Figure 21) and *President Coolidge* in 1931. These also were powered with synchronous motor drive. Costing $8,000,000 each, they were the largest passenger liners built in the United States, being 654 feet long, 81 feet beam, 31,063 tons displacement, and 20.5 knots speed. B. & W. header type boilers furnished steam and radio broadcast speakers were an innovation. In the summer of 1933 the *Manhattan,* largest passenger vessel built in the United States, was delivered, with reduction gears and turbines for propulsion.

Small Diesels also found their field, the Coast Guard building a series of 165-foot patrol boats of 16 knots in 1931. Powered with Winton Diesels, they formed a compact unit, the main generators being direct connected to the main engines with a combination hand and power Sperry steering system actuating the twin rudders. In 1922 the Navy began replacing its old Norfolk engines for small boats with a modified Van Blerck gasoline engine. The hazard of gasoline remained and in 1929 replacement studies of the gasoline engines began, when the Navy acquired rights to

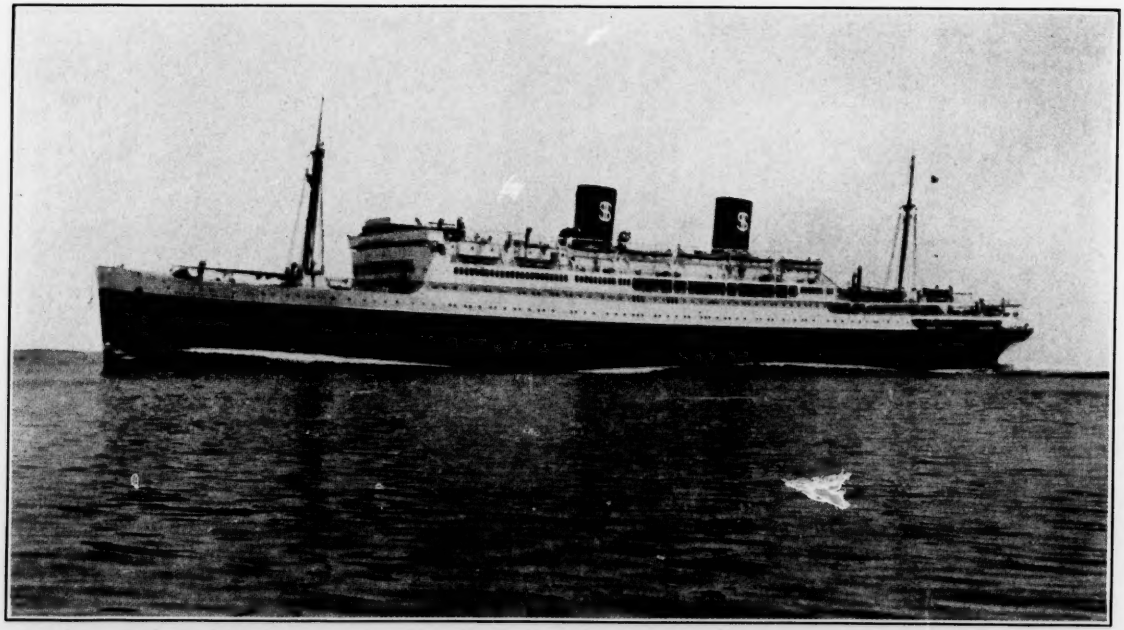


THE "EUROPA" AND "BREMEN" AT BREMERHAVEN.
(The *Europa* is at the Quayside.)
FIGURE 19.



M. A. N. Double-Acting Two-Stroke Cycle Diesel Engine of 11,700 B.H.P.—View from Starting-Platform Position.
Figure 20.

M. A. N. Double-Acting Two-Stroke Cycle Diesel Engine of 11,700 B.H.P.—View from Starting-Platform Position.
Figure 20.



Courtesy Newport News Shipbuilding and Drydock Co.

S. S. "President Hoover."
Figure 21.

build a Buda Diesel engine for this purpose and the consequent elimination of the gasoline hazard. The search for suitable engines occupied four years and in 1934 the Navy began the manufacture of its own engines under a policy that furnished all new construction with Diesel engines and gradually replaced those in older ships.

By 1932 the water tube boiler was definitely adopted for all merchant vessels, few, if any, Scotch boilers being built. The *Viceroy of India,* an English ship, was equipped with side-fired Yarrow boilers on the order of the U.S.S. *Farragut.* The *Empress of Britain,* a contemporary, was the largest vessel built in Great Britain since the World War. Her boiler plant included one Johnson boiler which was claimed to generate steam at a rate of 10 pounds per square foot of heating surface with a maximum rate of 13 pounds. Her title of "biggest" was short-lived, for the *Queen Mary,* launched in September, 1934, immediately usurped the title and also established a record launching weight. She has since been outclassed by the *Queen Elizabeth,* now launched and completed.

Prior to the completion of the *Queen Mary,* the French completed the first 1000-foot liner to go into commission. The *Normandie* had the largest electric drive plant ever to be placed on a merchant vessel, 160,000 horsepower capable of maintaining a 30-knot speed. Twenty-nine Penhoet water tube boilers furnished steam. Meanwhile the Italians entered the race of superliners and built the *Rex,* a steam-driven passenger vessel. These ships, in their competition consistently lowered the trans-Atlantic record in succeeding passages. Not to be further outdone, Italy also built the *Vulcania* and *Saturnia* with twin Diesels developing 16,500 brake horsepower on trial. These engines, rated as the largest marine oil engines in the world, were of the two-stroke, double-acting design, with two separate scavenging pumps. A speed of better than 21 knots was attained. In the freighter group all countries participated, Japan supplying the lead with 18½-knot tankers. In the United States the newly created Maritime Commission supplied funds and preliminary plans for a series of 13½-knot cargo ships and a group of twelve 18½-knot tankers with geared turbines. At this writing, October, 1938, the United States is building more ships than at any time since 1920.

As the old order changes we see many old friends depart. The liners *Majestic, Mauretania,* and *Leviathan* have gone to the scrap heap during the past five years to be used again in the building of others. The *Morro Castle,* which had all known safeguards for the lives of passengers, brought horror to all in a severe fire, the greatest marine tragedy since the *Titanic* sinking in 1912. As stated in a previous article, disaster may indicate the road to improvement and a world-wide service result through cooperative effort to prevent a repetition. This has been true in the United States with the Bureau of Standards, Bureau of Navigation of the Department of Commerce, Board of Steamboat Inspectors, Bureau of Lighthouses, the Maritime Commission, Navy Department, and various groups of marine underwriters cooperating to make tests on safety requirements for ship construction, cargo, equipment and stowage.

The future of naval engineering design? There is no venture of a prophecy as the work continues apace and engineering skill improves. Ships are growing and with them their power plants. Today's biggest and best is shortly on tomorrow's scrap heap.

CHARLES P. WETHERBEE—BIOGRAPHY.

By W. S. Newell.*

It is with deep regret that the Society has learned of the death of Charles P. Wetherbee. For many years he was a leader in the development of marine engineering in this country and abroad. The loss of his conservative judgment is a matter of serious concern. It is felt that the concise account of his career presented here by his close associate, Mr. Newell, will be of timely interest to readers of the Journal *and a source of inspiration to those who carry on.*

Charles P. Wetherbee was born in the city of Detroit, Michigan, on February 18, 1871, the son of George C. and Mary Phelps Wetherbee. His father served as a captain with the Union forces during the Civil War. His boyhood was spent largely in and about Detroit. In the fall of 1887, he entered the Massachusetts Institute of Technology in Boston, graduated in 1891, and in that same year was appointed an instructor in Naval Architecture at the Institute.

In 1892 he went to Paris, France, and entered the Ecole d'Application du Genie Maritime from which he graduated in 1894. While in France he was employed during vacation from the Genie Maritime, at the Chantiers et Ateliers, Augustin-Normand at Le Havre, France. Mr. Wetherbee's work at the Institute of Technology, his advanced work at the Genie Maritime, together with practical work at the Normand works at Havre, laid the foundations upon which he was to build a notable career for himself later as a Naval Architect and Marine Engineer, in both branches of which he did brilliant work. Upon graduating from the Genie Maritime he returned to the United States and was attached to the Superintending Naval Constructor's office

* President, Bath Iron Works Corporation, Bath, Maine.

at the Newport News Shipbuilding and Dry Dock Co. at Newport News, Virginia.

On January 14, 1896, he married Katherine Ellen Brown at Reading, Massachusetts, and about that time became associated with the Columbian Iron Works at Baltimore, Maryland, where naval construction work was underway.

Late in 1896, the U. S. Navy was preparing to build torpedo boats and torpedo boat destroyers on a larger scale than heretofore. The Bath Iron Works, Ltd., through its founder and president, the late General Thomas W. Hyde, became interested in the proposed new construction, and in preliminary conferences at Washington, and with Sir John H. Biles of Glasgow, was advised to consider seriously building under licenses from Augustin Normand at Havre, France. This was done and resulted in an arrangement between the Bath Iron Works, Ltd., and the Chantiers et Ateliers, Augustin-Normand and the coming to Bath of the subject of this biography, as he was familiar with the French firms' work, and unusually well fitted by his own attainments to handle this new design and construction in this country. Five torpedo boats were built for the U. S. Navy by the Bath Iron Works, Ltd., under Mr. Wetherbee's supervision, which were probably the most successful of the early craft of this type built for the Navy. These were the *Dahlgren, Craven, Bagley, Barney,* and *Biddle,* the first thirty-knot vessels built for the Navy.

Along in 1904 when the Navy was considering building three scout cruisers, which afterward became the *Chester, Birmingham,* and *Salem,* the Bath Iron Works being interested in this new construction, and planning to bid for the construction of one of these cruisers, Mr. Wetherbee, prepared several base designs to submit to the Navy, all with reciprocating engines, and went to Havre for consultation with Augustin Normand regarding the propelling machinery he proposed using. It was during this visit that M. Normand suggested that while he was in Europe he should look into the Parsons turbine before returning to America. In London, on his way to Newcastle to investigate the Parsons turbine, which had by that time made some successful marine applications, he met Sir John H. Biles who confirmed M. Nor-

mand's report to Mr. Wetherbee of the apparent growing importance of the turbine. Sir John H. Biles also informed Mr. Wetherbee that the British Admiralty had, within a few days, decided upon the use of the turbine for all new combatant ships for the Royal Navy. Mr. Wetherbee continued on to Newcastle, looked over the turbine situation, and then and there concluded a license arrangement between the Parsons Marine Steam Turbine Co. and the Bath Iron Works, Ltd. Bath later, upon Mr. Wetherbee's return, bid for and was awarded a contract to build the Scout Cruiser *Chester* which had Parsons turbines, and was the first vessel in the U. S. Navy to be so equipped.

The subject of this biography was responsible also for the machinery designs of the U. S. Battleship *Georgia,* and all of the turbine driven destroyers built at Bath up through 1920, in which vessels were outstanding machinery designs for which Mr. Wetherbee was solely responsible. One of his most daring and successful machinery designs was the design, construction and installation of geared turbines in the U. S. S. *Wadsworth,* the first in the Navy.

In 1911, he was advanced at the Bath Iron Works from Superintending Engineer to Vice President and Superintending Engineer, in which capacity he remained until 1923, when he retired. A few years later, he was consultant for the Westinghouse Electric and Mfg. Co., and still later acted in a similar capacity with the Bethlehem Shipbuilding Corporation.

During the World War, Mr. Wetherbee served as a member of the Sagadahoc County Public Safety Committee, and in an advisory capacity with the Navy Engineers at the Navy Department at Washington. He was at one time President of the Bath Savings Institution, Trustee of the Old Ladies Home, the Old Folks Home at Bath, the Bath Memorial Hospital, the Pattern Free Library, and a director of the Bath branch of the American Red Cross. Through his father, Captain Wetherbee, he was a member of the Loyal Legion.

Mr. Wetherbee became a member of the Society of Naval Architects and Marine Engineers in 1900, served as a Council Member from January, 1916, to December, 1918, became a Vice President in January, 1919, and remained as such until December,

1931, when he was elected an honorary Vice President. Mr. Wetherbee became a life member of the Society in November, 1918.

He became a civil member of the American Society of Naval Engineers on March 24, 1910, and remained a member until the date of his death. During the calendar year 1933, Mr. Wetherbee served the Society as a member of its Council.

Mr. Wetherbee was a member of the following Societies: Institution of Naval Architects (Great Britain), North East Coast Institution of Engineers and Shipbuilders (Great Britain), and the Association Technique Maritime (French).

With the sudden death of Mr. Wetherbee on August 9, 1938, at his home in Bath, Maine, there was closed the life of a brilliant and eminent engineer, a valuable citizen, and a most beloved friend to all who knew him.

NOTES.

INDEX TO NOTES.

Welding of Carbon-Molybdenum High-Pressure Power Piping.
—The Welding Engineer, Chicago, Ill., July and August, 1938.

Medium and High Speed Diesel Engines for Marine Service.
—Transactions, Institution of Engineers and Shipbuilders in Scotland, May, 1938.

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—The Metallurgist (Supplement to the Engineer), London, England, August 26, 1938.

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Grading Welders.
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WELDING OF CARBON-MOLYBDENUM HIGH-PRESSURE POWER PIPING.

The following article is reprinted from the July and August, 1938, issues of The Welding Engineer, Chicago, Ill. It represents a digest of the procedure data contained in Bulletin No. 20, "Welding of High-Pressure, High-Temperature Piping," recently issued by Metal and Thermit Corp., 120 Broadway, New York, N. Y. The paper is based on the supposition that the performance of flanged joints is unreliable when used with steam of high pressure and temperature, whereas welded joints are free from service trouble and maintenance expense, permit changes and additions to be made readily, and make easier the application of insulation. The various steps of designing, welding, heat treatment, and testing are traced.

Only since the perfection of heavy coated electrodes has it been possible to obtain weld metal free of oxides and nitrides and having physical properties equal in every respect to those of the parent metal. The development of carbon-molybdenum electrodes, for example, which provide welds with all of the strength, ductility and creep resistance of the low-alloy steel piping employed for high-temperature, high-pressure service, has led to a number of installations of welded power plant piping.

Without exception, carbon-molybdenum steel piping is used for high-pressure, high-temperature lines in such installations. This steel is to some extent corrosion resisting. Its most important characteristic, however, is high strength and resistance to creep at elevated temperatures. The chemical analysis of carbon-molybdenum steel is generally specified as follows:

Carbon	.10 to .20 per cent
Manganese	.30 to .60 per cent
Silicon	.10 to .20 per cent
Molybdenum	.40 to .60 per cent
Phosphorus	.04 per cent max.
Sulphur	.05 per cent max.

Typical physical properties of such a carbon-molybdenum steel are:

Yield point	45,000 psi.
Ultimate strength	75,000 psi.
Elongation in 8 inches	20 per cent
Reduction of area	40 per cent

In addition to the selection of proper electrodes, there are three principal factors contributing to successful pipe welding. Because of the very nature of the work, it is essential, of course, that each and every weld be flawless and have the required physical properties. Such results can be obtained only when—

1. The weld design is correct.
2. A suitable welding technique is evolved.
3. A welding procedure and the welding operators are properly qualified.

A number of different types of welded joints for pipe lines have been designed and employed in the installations to date. Some of these designs call for recessed and raised bead backing strips or chill rings; others involve upsetting of the pipe ends to permit recessing of the chill ring in the pipe wall without reducing the cross section at the weld; and still others require machining of pipe edges to form "U" grooves and bevels with lips of varying dimensions.

Good welds may be produced and entirely satisfactory results have been obtained with any of these designs. All things considered, however, the primary requisite of any weld design is weldability and, as a general rule, the more simplified the design, the easier it becomes for operators to produce sound and satisfactory welds.

BASIC JOINT DESIGN.

From this standpoint, the basic design, shown in Figure 1, possesses many advantages. This design is intended for welds in plain carbon steel or carbon-molybdenum steel piping 2½ inches or more in diameter in the horizontal

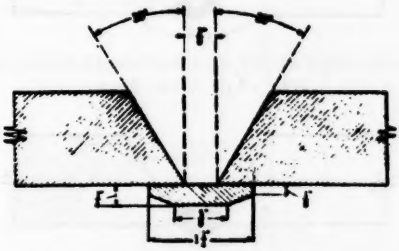

FIGURE 1.—BASIC PIPE JOINT DESIGN.

rolled, or "A" position and the horizontal fixed, or "B" position. It calls for a 30-degree straight bevel of each pipe edge with no lip, with a plain chill ring of proper dimensions, and with a ⅜-inch gap at the root of the "V."

The chill ring is an essential feature of all pipe weld designs. Its purpose is to prevent formation of icicles and weld spatter inside the pipe and to provide complete fusion at the root of the weld. Chill rings are generally made of the same material as the pipe being welded. Since pipe walls may vary slightly in thickness and pipe is seldom perfectly round, it is frequently necessary, when using chill rings, to machine the pipe ends in order to provide true round inside contours and assure a good fit for the rings.

The ⅜-inch gap at the root of the "V" is recommended, because, while perfectly satisfactory welds can be made with smaller gaps, the larger space permits better manipulation of the electrode during welding, makes easier the laying down of the first few beads, which are usually the most difficult, and results in better welds.

The chill ring is not recessed in the pipe wall in this design, because in an investigation made for the Detroit Edison Co., at the University of Michigan, it was definitely determined that the slight reduction in inside diameter of the pipe caused by an unrecessed chill ring has no appreciable effect on steam flow. The additional expense that recessing entails, as well as any need for upsetting the pipe ends to compensate for reduced wall thickness, are thus avoided.

For several reasons the design is an improvement over those calling for "U" grooves or "V's" with pipe ends beveled to provide lips at the root of the "U" grooves, or in a "V" with lips, it is necessary for the welder not only to melt away the edge of each lip, but also, and at the same time, to penetrate into both pipe wall and chill ring. This is not always a simple

matter, particularly where the gap is too narrow to permit easy manipulation of the electrode, or in welding on the underside of a pipe in the horizontal position, where it is difficult for the welder to watch the arc.

Actually, the results of many tests show, for example, that other things being equal, more defective welds can be traced directly to this particular condition than to any other source. Figure 2 (A and B) indicates the difficulty of producing sound deposits with welds of such design and shows how

FIGURE 2A.—EXAMPLE OF WELDING DIFFICULTY WHERE A V GROOVE HAS A LIP AT THE ROOT.

FIGURE 2B.—WELDING DIFFICULTY WHERE A U GROOVE HAS A LIP AT THE ROOT.

readily slag is entrapped and cold-shuts occur. Figure 3, on the other hand, shows how, with straight beveled pipe ends and a gap of ample width, the welder can easily produce sound, clean deposits at the root by penetrating slightly into the chill ring and washing lightly up the pipe wall, first at one side of the root and then the other.

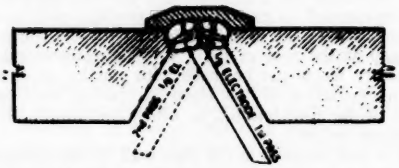

FIGURE 3.—WITH STRAIGHT BEVELED PIPE ENDS, THE WELDER CAN DO A BETTER JOB.

For welds in the vertical, or "C" position, the design is modified, as shown in Figure 4. The bevel of the lower pipe edge is reduced to approximately 7 degrees, while that of the upper pipe edge is increased to about 45 degrees. The gap remains at $\frac{3}{8}$ inch. This design for vertical welds provides a nearly horizontal shelf for the operator to build on and makes every bead deposited practically a fillet weld. The welding technique is that of continuous fillet welding.

It is recommended that the design for horizontal welds, shown in Figure 1, be employed for all welding on pipe in the horizontal position, as well as on pipe up to an angle of 30 degrees from the horizontal. Where the pipe to be welded is inclined at an angle of more than 30 degrees from the horizontal, the design for vertical welds, shown in Figure 4, should be used.

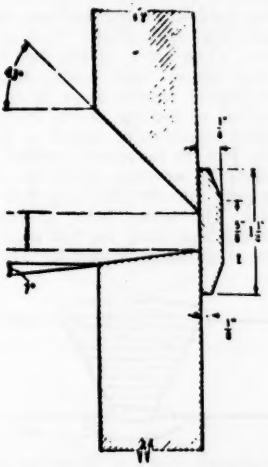

FIGURE 4.—MODIFIED DESIGN FOR WELDS MADE IN THE VERTICAL POSITION.

For welds in the smaller diameters of both carbon-molybdenum and mild steel pipe, a 60-degree included "V" design of weld, similar to that shown in Figure 1, but with a 3/16-inch to ¼-inch gap and a ⅛-inch-thick chill ring, may be employed in all positions.

WELDING PROCEDURE.

When welding thick walled pipe, the deposition of a number of thin layers of weld metal by means of a multiplicity of passes is preferable to the use of a few heavy layers and a small number of passes. More satisfactory welds are thus assured. Such practice eliminates the possibility of porous weld metal and, at the same time, because of the refining effect of succeeding deposits upon each layer put down, a better grain structure throughout the weld is provided. On carbon-molybdenum pipe ⅛-inch alloy steel electrodes are employed for the first two layers and the 5/32-inch size for each of the succeeding layers. When welding in the horizontal fixed position, the ⅛-inch electrodes are used at approximately 90 to 100 amperes and the 5/32-inch electrodes at 130 to 160 amperes. Where the pipe is rolled during welding, or, when welds are being made in the vertical position, slightly higher current values are employed. For corresponding applications on mild steel pipe mild steel electrodes are used in the same sizes and at approximately the same amperages. In all cases the weld deposit is built up to approximately 1/16

inch beyond the outside of the pipe before the cover layer is applied. Proper grain refinement in the weld for the full thickness of the pipe wall is thus assured.

When making a weld of the design shown in Figure 1, the backing ring is inserted in position in one pipe end and tack welded at several points along its inside edge. The end of the adjoining pipe, valve, or fitting is then brought into position, slipped over the free end of the ring and tack welded in place, leaving a 3/16-inch space between the beveled edges at the root of the gap. These tack welds in the "V" are made with a 1/8-inch electrode at 115 amperes. The arc is struck and the electrode withdrawn slowly, leaving flat "shoe button" tack welds, which do not require chipping out later, but are readily washed away when the first welding bead is put down. This method of tacking avoids any possibility of injury to the chill ring, which might otherwise be caused by the chipping hammer.

In shop work, where pipe in horizontal position is rotated as welded, the first layer is deposited by weaving across the entire width of the gap at the root, penetrating well into the chill ring and washing lightly up the pipe walls at each side. The second layer is then deposited directly on top of the first layer and is also made the full width of the gap. Succeeding layers are put down as shown in Figure 5. The electrode may be held

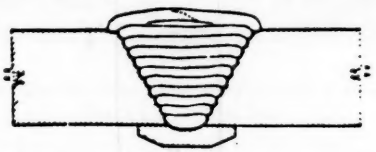

FIGURE 5.—HOW MULTI-LAYER WELD IS MADE IN THE SHOP ON PIPE IN THE HORIZONTAL ROLLED POSITION.

perpendicular to the pipe, or inclined toward the welder at about 30 degrees off the vertical and slightly ahead of the top dead center of the pipe, allowing the slag to flow back of the deposited metal as the pipe rotates. In general, the perpendicular position is employed when high amperages are being used, while the inclined position has advantages when using relatively low amperages. Figure 6 illustrates the manner in which the electrode is held.

HORIZONTAL FIXED POSITION.

Welds on horizontal pipe in the field, where the pipe cannot be rotated, require a somewhat different technique. The first part of the weld is made at the 60 degree sector, measuring approximately 30 degrees each side of the bottom dead center of the pipe, as shown in Figure 7. The initial deposit is a bead confined to this sector and made as a fillet, fusing the backing strip and the pipe wall on one side of the root of the gap only. The second deposit is run both ways from the bottom dead center of the pipe and is put down in the same manner as the first bead, but on the opposite side of the gap and up to the 30 degree point only. From this point it is continued as a full width layer up to the top dead center of the pipe on each side. The third deposit is also run both ways from the bottom center of the pipe and covers the first two beads, as shown in Figure 3, while succeeding layers are made, as shown in Figure 5. This method of welding

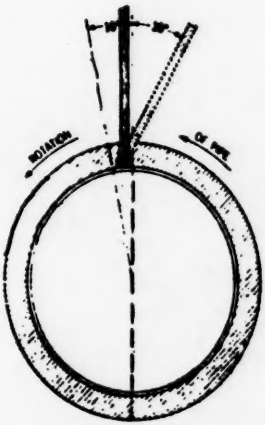

FIGURE 6.—HOW ELECTRODE SHOULD BE HELD WHEN PIPE IS IN HORIZONTAL ROLLED POSITION.

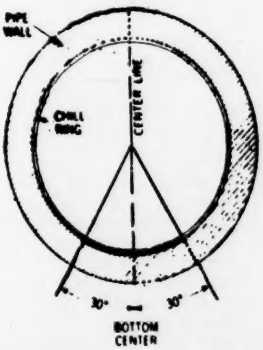

FIGURE 7.—WHERE THE WELD IS STARTED ON HORIZONTAL PIPE IN FIXED POSITION.

eliminates the usual difficulties encountered on the underside of pipe in the horizontal fixed position, where frequently, it is impossible for operators to watch the arc and where, therefore, a majority of defects ordinarily occur.

Welds in the vertical or "C" position are begun, as shown in Figure 8. The first deposit is a bead, penetrating the chill ring and lower pipe wall; a second bead penetrates the chill ring and upper pipe wall and fuses with

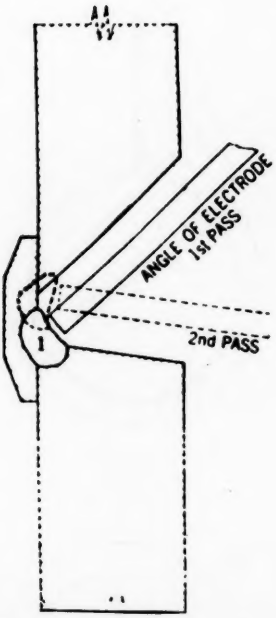

FIGURE 8.—HOW THE WELD IS STARTED ON PIPE IN THE VERTICAL FIXED POSITION.

the first bead; succeeding deposits are put down as illustrated in Figure 9, each bead being very nearly a perfect convex fillet weld. Care is taken in all of this welding to remove the slag thoroughly and to clean each bead or layer before the succeeding deposit is put down. This is done with a wire brush or a light hammer, following which the weld metal is smoothed with a chipping tool. The chipping operation may result in a slight peening effect, but is purely a means of cleaning and smoothing and possesses no value, as far as stress relief or grain refinement is concerned. The final or cover layer may be chipped smooth and peened lightly to give a finished appearance similar to knurling.

PREHEATING OF JOINT.

Preheating is not necessarily an essential part of the procedure. Its purpose is to reduce the rate of heat conduction away from the freshly deposited metal, and to aid in refining the deposit so that coarse grain formations in the weld are avoided. The same objectives may be accomplished under ideal conditions without preheating, when highly skilled operators, using a well developed technique, are employed. Nevertheless, under ordinary circumstances it is usual to preheat the welding ends of all pipes, valves and

fittings of both carbon-molybdenum steel and mild steel ½ inch thick or more. Customary preheating temperatures are from 400 degrees to 600 degrees F., and heat is maintained in the work while actual welding is going on. It is not considered necessary, however, that the preheating temperature be maintained during intervals between welding operations or during the interval between completion of the welding and the start of stress relieving.

A comparison of the physical properties of three individual weld specimens, one of which was neither preheated nor stress relieved, one of which was preheated but not stress relieved, is shown in Table 1, which indicates the effect of preheating when welds are made under ordinary conditions by operators of normal skill but do not indicate average results.

TABLE 1—EFFECT OF PREHEATING AND STRESS-RELIEVING.

TESTS OF THREE WELDED SPECIMENS

Specimen No. 1.....No preheat or stress relief
Specimen No. 2.....No preheat, but stress relieved at 1150 degrees for one hour and 45 minutes
Specimen No. 3.....Preheated 400 degrees to 500 degrees, but not stress relieved

TENSILE TESTS	*Tensile Strength*
Specimen No. 1	66,470 psi.
Specimen No. 2	60,230 psi.
Specimen No. 3	65,500 psi.

FREE BEND TESTS	*Elongation*
Specimen No. 1 (1/16 in. fracture at 90 degrees bend)	27.7 %
Specimen No. 2 (180 degree bend, no fracture)	26.4%
Specimen No. 3 (180 degree bend, no fracture)	43.8%

REVERSE BEND TESTS

Specimen No. 1.....O.K. through 180 degrees, slight opening on one edge
Specimen No. 2.....O.K. through 180 degrees, slight opening on one edge
Specimen No. 3.....O.K. through 180 degrees

NICK BREAK TESTS

Specimen No. 1.....Good fusion, no porosity
Specimen No. 2.....Good fusion, no porosity
Specimen No. 3.....Good fusion, no porosity

Preheating of welds in low-pressure lines may be done with gas torches, in which case the heat of the arc and an occasional application of the torch are depended on to maintain the necessary temperature in the pipe during welding. On high pressure lines in carbon-molybdenum steel pipe, however, where closer control of temperatures is required, preheating is done electrically. Pipe ends are enclosed in resistance or induction heaters and covered with a heavy coating of plastic insulation, leaving exposed only the surfaces to be welded. This procedure assures uniform preheating and maintenance of heat during welding. The insulation not only helps the parts to retain heat, but also protects the welder and permits using the same equipment for stress relieving without change or interruption.

STRESS RELIEVING.

To insure the elimination of locked up stresses, all welds in material ½ inch thick or more, requires stress relieving. As a general rule, because of the creep-resisting properties of carbon molybdenum steel, welds in carbon-molybdenum pipe require somewhat higher stress relieving temperatures than those in mild steel pipe.

The stress relieving procedure consists in bringing the welded joint slowly up to the proper temperature and holding it there for approximately one hour per inch of wall thickness of pipe. The recommended stress-relieving

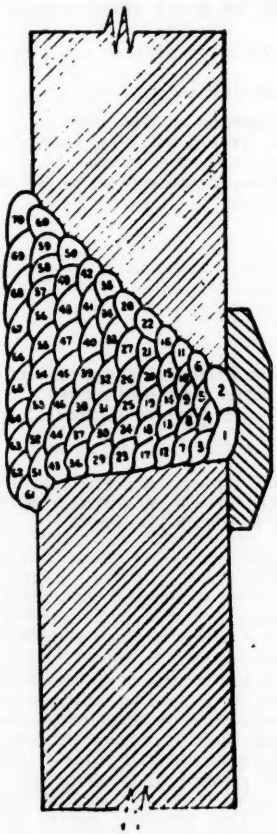

FIGURE 9.—HOW SUCCEEDING BEADS ARE PUT DOWN ON JOINTS IN THE VERTICAL FIXED POSITION.

temperature for carbon-molybdenum steel pipe is 1200 to 1250 degrees F., while for plain carbon steel pipe ample stress relief will be obtained at 1150 to 1200 degrees F. The distance along the pipe included in the heated zone is generally six times the wall thickness of the pipe each side of the weld. The heated zone is usually not allowed to cool more rapidly than 250 degrees an hour between 1200 degrees and 600 degrees. When 200 degrees has been reached the insulation may be removed and the pipe allowed to cool in still air at atmospheric temperature.

Comparative free bend elongations and hardness of adjacent sets of carbon-molybdenum weld specimens, stress relieved at 1150 degrees and 1200 degrees indicate that advantages are gained through the use of higher temperatures.

Stress relieving of joints which have been preheated electrically is conveniently done immediately after completion of welding.

Stress relieving of joints which have been preheated electrically is conveniently done immediately after completion of welding. Additional insulation is placed around the weld and the current is stepped up to provide the proper temperature. Where electrical preheating has not been employed, electric induction or resistance stress-relieving equipment is usually used. The weld is brought up to proper temperature and allowed to cool at the usual rate of not more than 250 degrees an hour.

QUALIFICATION OF PROCESS.

Because of the necessity for having every weld in the piping system of uniform high quality, it is of utmost importance that a standard welding procedure covering all types of welds involved be developed and strictly adhered to. The American Welding Society Tentative Rules for Qualification of Welding Process and Testing of Operators, as revised in June, 1937, provide an excellent guide for establishing and recording, as a process specification, the definite limits of all essential variables. Chemical analyses and physical properties of all parent metals to be used in construction, trade and manufacturers' names of filler metals, design of all welds to be employed, preparation of base materials, welding technique and preheating, and stress-relieving procedure, should all be definitely specified in the process specifications.

The American Welding Society rules may also be followed in investigating the process and determining its ability to produce welds with the required tensile strength, ductility and soundness, as well as in qualifying both the process and the welding operators.

The method to be employed in qualifying the process and the operators should also be written into the general specifications for every project.

In qualifying the welding procedure under the above rules, the fact that welding technique may vary to suit three distinct conditions is taken into account; (1) pipe in the horizontal fixed or "B" position, requiring three-position welding; (2) pipe in the horizontal rolled or "A" position where pipe is rotated during welding; (3) pipe in vertical or "C" position, requiring only horizontal fillet welding.

Three pairs of complete specimen welds are first made up. Each pair consists of one weld made in pipe of the minimum wall thickness to be used in construction and one specimen weld made in pipe of the maximum wall thickness, except that the thickness of the pipe used for the second specimen need not exceed 1½ inches. One pair of these specimen welds is made in the horizontal fixed position, another pair in the horizontal rolled position, and the third pair in the vertical position. If, however, the welding technique and design to be employed in the two horizontal positions is the same, the specimen welds made in the horizontal rolled position may be omitted.

From each of the sample welds ten coupons or test specimens are removed and prepared for testing:

2 Reduced section tensile specimens.
2 Free bend specimens.
2 Side break specimens.
2 Nick break specimens.
2 Etch specimens.

For horizontal fixed position welds, these specimens are removed and prepared in the order shown in the pipe section Figure 10. For welds made in other positions they may be taken in any order, except that no two specimens of the same type are removed adjacent to each other. The specimens are

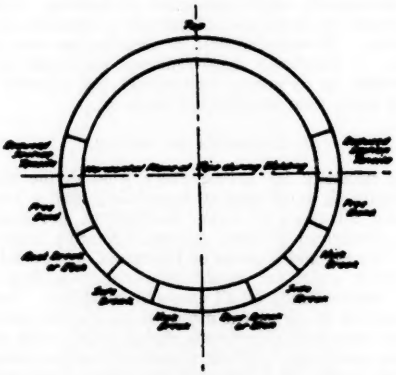

FIGURE 10.—WHERE TESTS SPECIMENS ARE REMOVED FROM SAMPLE WELDS TO QUALIFY THE PROCESS (HORIZONTAL FIXED POSITION).

tested in accordance with the methods described in the American Welding Society Rules and shown in Figure 11. Reduced section tensile specimens are intended to show strength and soundness of welded joints, and the tensile strength of the weld metal in such specimens should be at least equal to the minimum specified tensile strength of the pipe. Free bend tests are designed to show the ductility of the filler metal and such specimens should show an elongation of at least 30 per cent. Root-break, side-break and nick-break specimens are made for the purpose of investigating soundness of deposit. They should show in the fractured surfaces, complete penetration throughout the entire thickness of the weld and total absence of oxide and slag inclusion, cracks and lack of fusion and root penetration. A limited number of small gas pockets (1/16 inch in diameter or less) is permissible, the general rule being not more than six to a square inch.

If desired, instead of the above rules, the testing methods outlined in the Code for Pressure Piping of the American Standards Association may be followed in qualifying the welding procedure.

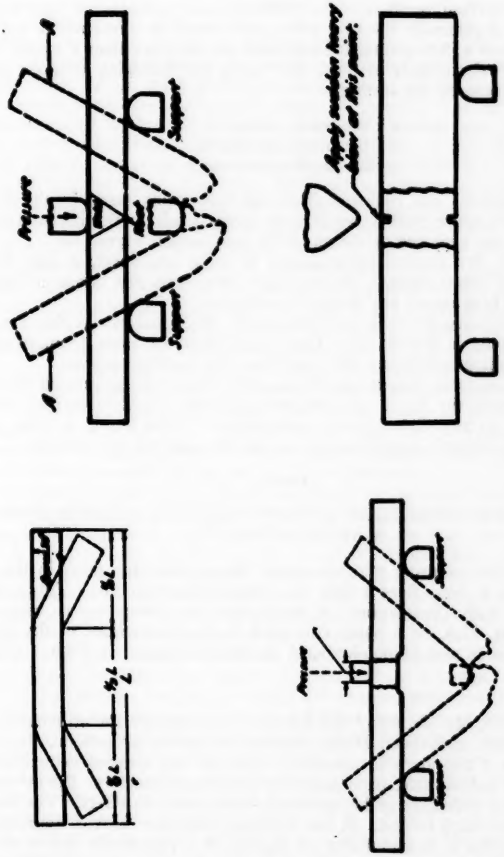

FIGURE 11.—PHYSICAL TEST SPECIMENS REQUIRED IN THE QUALIFICATION OF THE WELDING OPERATORS.

QUALIFICATION OF OPERATORS.

Having established by the above tests that the welding process is satisfactory, the next step is the testing and qualifying of welding operators to determine their ability to produce welds of the desired quality.

Qualifying tests for operators are limited to those intended for determination of lack of soundness in the weld. Testing may be done in accordance with either the American Welding Society Rules for Testing of Welding Operators, or the Code for Pressure Piping of the American Standards Association.

When the American Welding Society Rules are being used, each operator is required to make one test weld in the horizontal fixed position and one test

weld in the vertical position. The diameter and thickness of pipe used for these welds is generally the maximum to be used in construction, but must not be less than 4 inches standard and need not be more than 8 inches double extra heavy. From each of these test welds the following coupons are removed and prepared for testing:

2 Face-bend specimens.
2 Root-break specimens.
2 Side-break specimens.

These specimens are removed from the test welds made in the vertical position in the order named, while from welds made in the horizontal fixed position they are removed as shown in the pipe section Figure 10.

In addition, for further investigation of weld soundness, a pair of etch specimens are often made. The etch test specimens are taken at locations which would best reveal any lack of soundness.

All specimens are tested in accordance with the American Welding Society Rules, as shown in Figure 11. They must meet the same requirements as the corresponding specimens for qualifying the welding process.

In case an operator fails to qualify, he may either take an immediate retest, or may postpone the retest for one week in order to obtain further training or practice. At any time during construction, if there is any definite reason to question a welder's qualifications, he may be required to requalify.

MEDIUM AND HIGH-SPEED DIESEL ENGINES FOR MARINE SERVICE.

The possibility of using multiple small Diesel generator units in the main drive plant of a ship offers a field for interesting conjecture. This question is discussed with illustrations of application to low-powered vessels by E. P. Paxman, M.A., in a paper contained in the transactions of the Institution of Engineers and Shipbuilders, in Scotland, Volume 81, Part 7 of May, 1938.

When in 1933, Mr. Ricardo * put forward his proposals for utilizing a large number of small high-speed Diesel engines for marine propulsion, they were received with a considerable amount of interest and excited criticism, both favorable and unfavorable, from many knowledgeable quarters. But even today there is no real indication of his proposals being put into effect. The reasons for this are not hard to find. It has in actual fact been proved impracticable to couple together a large number of engines, if a reasonable degree of simplicity is to be retained. Ricardo's arguments may be said to fall basically into two groups; firstly, his plea for light-weight high-speed engines, and secondly, his suggestion to make use of a large number of small engines. It is probable that the second argument was necessary to support the first, because at that time there were not readily available any well-developed high-speed engines of larger output than those referred to. Today, however, there are new types made specially for traction and marine purposes.

In other spheres, notably in aviation, where the use of high-speed engines is essential, it is clear that when big aggregate powers are called for, preference is always for large units to make up that aggregate. An excellent example of this is in the big flying boats built for Imperial Airways. These

* Proc. I.Mech.E., 1933, vol. 125, p. 293.

boats have a total "take off" horsepower of 4000 and are provided with four Bristol engines of the Pegasus type. In a flying boat there is not the complication of having to couple the engines together as in marine drives, and it is clear, therefore, that there are sound reasons for electing to have larger engines rather than a great number of small ones. But in this example, as in many others, high power does not mean low speed. The Bristol Pegasus engines referred to have 9 cylinders, each of 5¾-inch bore and 7½-inch stroke, and develop their take-off power of 1010 H.P. at 2675 R.P.M. Their normal running speed in service is probably about 2200 R.P.M., and their horsepower under these conditions 700. These figures correspond, under take-off conditions, to a brake mean effective pressure of 170 pounds per square inch with a piston speed of 3350 feet per minute, and in continuous service conditions to a brake mean effective pressure of 145 pounds per square inch with a piston speed of 2750 feet per minute. These figures are generally similar to those of the latest Rolls-Royce Merlin engines which normally develop a maximum B.H.P. of 1050 in a 12-cylinder V engine, with a bore of 5 7/16 inches and a stroke of 6 inches at a speed of 3000 R.P.M., and in continuous normal flight, they run at from 2200 to 2400 R.P.M., giving the corresponding mean effective pressures of 166 and 145 pounds per square inch at piston speeds of 3000 and 2300 feet per minute, respectively. In aero engine design there are two factors that normally are of practically no importance in marine service. The first is the question of frontal area which constrains the designs in many respects and necessitates the smallest possible overall dimensions, and the second is the deadweight.

In the design of high-speed Diesel engines today, it can be accepted that the designer need not be limited by the fear of obtaining imperfect combustion at any load or speed at which the engine can be made to run mechanically. This is a very wide statement, and therefore figures are given below in support of it. It may be properly argued that it is not sufficient to achieve good combustion at all speeds and loads, but it is equally important to have full control over the process of combustion and to regulate the maximum pressures and the fuel injection system pressures. At the same time, it is essential that the system should be one that is preferably self-regulating, that is to say, it should not require any manual or automatic adjustment of the injection timing; further, it should not demand exceptional workmanship or accuracy in the construction of the injectors, sprayers, or fuel pumps.

In the system employed in the engines to be described, these features are obtained by the use of the Ricardo Mark III Comet chamber. Many of the main features of the earlier Ricardo Mark II are today well known, but it is not always appreciated that one of the salient points has been the use of the heat insulated throat. The temperature of this throat rises with increasing output of the engine, either of M.E.P. or speed, and as the temperature rises it has the effect of reducing the delay angle between the commencement of injection and the commencement of combustion. As a result the firing pressures in the working cylinder are remarkably constant over a very wide range of load and speed. At the same time, by the employment of a large pintle jet, fuel line pressures are kept low. Injector nozzles are normally set at a pressure of 1500 pounds per square inch. Fuel pressures at speeds of 1500 R.P.M. are about 3000 pounds per square inch and at 1000 R.P.M. they are 2500.

The Ricardo Mark III Comet is a development of the earlier Ricardo Comets. The benefits of orderly and controlled rotational swirl are retained, as well as the advantages accruing from the use of a heat-insulated throat, and further, approximately only 50 per cent of the volume of air is contained

in the sphere or Comet proper, the remainder being contained in two flattened circular bowls shaped in the piston top. The whole of the fuel is admitted into the chamber by a plain pintle nozzle of the low-pressure self-cleaning type. It is there mixed and partially consumed with the air swirling in it, and finally emerges to continue its rotary motion in a horizontal direction in the two chambers in the piston top, where it burns the remainder of the air. The advantages of this arrangement are, firstly, that only half the air has to be forced through the Comet throat, so that the heat losses in transfer are reduced to approximately half those of the older type; secondly, a greater percentage of the proportion of air left above the piston can be consumed; thirdly, by suitably arranging the chambers in the piston top they serve as depressions into which the air and exhaust valves can open, so enabling any suitable valve timing to be used despite the fact that at top dead center the piston top is extremely close to the cylinder head. Finally, by reducing the size of the Comet in the head, a considerable distance is provided between the inlet valve seating, exhaust valve and Comet, and advantage can be taken of this fact to allow for directional water cooling in this vicinity, which is of the utmost importance where high outputs are being sustained for long periods. The system has been applied on engines of from 3¼ to 20-inch bore.

At all loads up to the extreme maximum the exhaust is completely invisible, there being not even a trace of haze. If the outputs are extended beyond that it will be found that the curves turn up very sharply and suddenly, but at that point the exhaust becomes dirty immediately. This is due to the very complete combustion taking place in the whole of the air reached by fuel, and it is only when there is a definite shortage of air that the combustion suffers. This is in sharp distinction to direct injection systems in which, after a certain M.E.P., the exhaust very slowly and steadily becomes greyer, due to the fact that there is still a considerable percentage of oxygen in the cylinder. The exhaust temperatures of the Mark III Comet combustion chamber are generally lower than with any other type. Due to the off-setting of the combustion chamber throat, the valves can be the maximum size and there is, of course, no restriction due to the air having to pass through any throat during its admission to the cylinder.

Generally, therefore, the system (1) allows full control of the injection process at all speeds and loads, (2) has no mechanical complication, (3) permits of attaining the highest volumetric efficiency, and (4) enables the greatest percentage of the inhaled air to be employed for combustion. Therefore, it can reasonably be maintained that by employing this system the designer of a modern high-speed marine Diesel engine is restricted purely by the thermal or mechanical stresses that can be tolerated with the main working parts of the engine, and he is free to run the engine at whatever speeds are considered practicable, exactly in the same way as the designer of an aero engine. While it is highly important in an aeroplane engine to reduce the weight by fractions of a pound per horsepower, such small savings are insignificant in a ship. The designer of a high-speed marine engine is, therefore, initially in a far more favorable position than the designer of an aeroplane engine. He can consider accessibility and convenience of arrangement and make use of relatively heavy and rigid sections, and he need not be driven to extremes of piston and rotational speeds which call for the employment of the costliest materials and the most expensive machining of parts. Since it is not essential for the marine engine to operate at such extremely high outputs as the aero engine, very much larger cylinders can be employed, without exceeding the limits imposed by the requirements of heat flow and piston temperatures.

With even very reasonable limitations of piston speed (say, 1500 feet per minute, it will be found that a very compact and relatively lightweight Diesel engine of the multi-cylinder type can be built, provided the design follows on rational lines. Making use only of commercial materials such as drop-forged 40-ton steel connecting rods, machined only in way of the bearings, and using white metal bearings and cast Y alloy pistons of normal construction, it will be found possible today to run at speeds up to 1500 R.P.M. with an engine having a bore of 7 inches and a stroke of 7¾ inches without imposing stresses in any way greater than usual. If the ratio of stroke to bore is increased to give a stroke of 10¼ inches, then the equivalent speed would drop to about 1100 R.P.M. If any other arbitrary piston speed is adopted, then the relative permissible speeds will be in the same ratio. By employing the shorter stroke, the benefits of the higher speed are obtained, and at the same time the majority of the moving parts become substantially smaller, lighter, and more readily handled.

Apology must be made for dealing principally in this paper with features of the design of high-speed engines from the range of those built by the Author's firm, but in mitigation it must be pointed out that, in this country at any rate, there is no other light high-speed engine in production which is capable of developing powers of the particular range discussed; in the larger medium-speed engines, there are many excellent examples whose main features are in general very similar. Here again where they are designed to be run at higher speeds, the majority of them embrace the system of combustion referred to above.

Among the range of engines referred to are two main series, each being built with the same bore with two different strokes. The first has a bore of 7 inches, and is built as a V engine with a stroke of 7¾ inches and as a straight vertical engine of the same bore, but with a stroke of 10¼ inches. The second series is built with a bore of 9½ inches and with strokes of 12 and 17 inches, respectively. It is of interest to consider the influence of these differing strokes on the weights and sizes of the parts of the respective engines. In each instance the pistons, gudgeon pins and small end bearings of the engines of the same bore are identical, as are the cylinder heads and valve gear. The connecting rods naturally differ with the strokes, the lengths being respectively 25 and 34 inches, and the weights 96 and 130 pounds in the 9½-inch bore series. In engines of 7-inch bore, the connecting rods differ somewhat in construction to permit of the two cylinders operating directly on the same crankpin. For the purpose of comparison, however, the center connecting rod may be used, and in this instance the lengths and weights of the rods of the two differing strokes are 16 and 20 inches, and 18 and 40 pounds. In all these instances the connecting rods are drop forgings of 40-ton steel, and within the normal speed ranges they are left unmachined in the webs.

On making use of the V type of construction together with the low stroke/bore ratio, it is a relatively simple matter to design an engine which, while retaining all the robustness of the engine of lower speed, will produce its power continuously in a very much smaller compass and with parts that are very much easier to handle.

It will be seen at once that without exceeding any higher rating, the V engine saves enormously in weight and in every dimension, and lends itself much more favorably to coupling up to any form of electrical generator or similar drive. But further, due to the smaller cylinders, it is permissible to run both at higher speeds and with higher ratings, and as an example of what has been achieved without undue difficulty, it may be mentioned that this cylinder size is capable of being operated at a B.M.E.P. of 150 pounds

per square inch at speeds up to 1750 R.P.M., which corresponds to a piston speed of 2260 feet per minute when supercharged to a pressure of 7 pounds per square inch. From these figures it will be appreciated that there is an enormous margin available, both mechanically and thermally, and that if we select an arbitrary piston speed of, say, 1500 feet per minute, which corresponds to only 1150 R.P.M. , and a B.M.P. of 115 pounds per squire inch when supercharged, the conditions are so well within the scope of the engine that they may be obtained continuously and employed as continuous and satisfactory ratings. Under these conditions a 12-cylinder engine will develop continuously 600 B.H.P. and the 16-cylinder engine, which consists of two banks of 8 cylinders, 800 B.H.P.

When considering these outputs it should be said that even without supercharging, the engines will develop at this speed a maximum B.M.E.P. of a little over 130 pounds per square inch. Superchargers can be driven either directly from the engine or by an independent motor. Owing to the extremely low cyclic variation and uniform torque, these engines can be run at speeds from idling to their maximum without a flywheel, and so flywheels are not provided. Between the engine and the generator a Wellman-Bibby coupling of a special type is normally provided, and the characteristics of this coupling are so arranged as to ensure freedom from torsional stresses throughout the required speed range. The coupling has the added merit of permitting axial movement of the engine relatively to the generator, and also of accommodating, to a certain degree, any malalignment that might arise in service due to movement of the seatings.

Where larger powers are required than can be conveniently arranged by combinations of 800-H.P. engine generating sets, it is possible to drive one alternator of double that power by an engine at each end, the Bibby coupling being interposed between each engine and the alternator. The advantages thereby obtained are, for a given power, a reduction in the number of alternators and simplification of the electrical control and switchgear or, alternatively, double the permissible output per group of engines, since it is only feasible for electrical reasons to link to one propelling motor, groups not exceeding six alternators. The characteristics of the sets outlined above are extreme smoothness of torque and an almost complete absence of vibration, very small headroom, and great accessibility.

It is interesting to compare the overall dimensions of the 800-H.P. V engine with those of the low-speed 800-H.P. Diesel generating sets installed in the *Lochfyne,* or of the later 650-H.P. sets installed in the *Lochnevis.* The latter are particularly interesting as being, it is believed, the first fully isolated spring-mounted Diesel propelling sets of anything like that power and size. Each group of engine and generator weighs 30 tons, and the result of the spring isolation is to eliminate entirely any signs of transmitted vibration of the machinery to the hull. The higher the speed of rotation, the greater the number of cylinders, and thus the more even the torque, the easier does it become to isolate the engine.

Another problem which is practically insuperable with larger engines is that of reducing to an acceptable level the noise in the engine room. This can be achieved with comparative ease with the high-speed V engine. Due to its small overall dimensions, a sound-proof casing is easily constructed. This need not consist of anything more elaborate than sheet steel casings sprayed on the inside with an adhesive form of asbestos. These casings can be mounted rigidly on the floor with the spring-mounted engine set running completely clear of them inside. The sides of the casing can be arranged to open either on hinges or to be removed bodily without any inconvenience.

All the gauges should be grouped at one end and all the pipework which, of course, should be flexible, can be removed through a suitable conduit which can be left permanently in place. Ventilation of the casing should be arranged, and this is particularly important if the alternator is also enclosed since, in that event, a considerable amount of heat will be liberated from it, and it is important to limit its temperature.

With engines of the dimensions given it becomes possible to consider engine room arrangements differing substantially from those normally employed. In day passenger boats or in vehicular ferries and similar craft, where the machinery must be situated in a space with limited headroom, the attraction is obvious. In coasters and tankers and similar vessels it becomes possible to mount the engines on a flat right aft above the propelling motors. The difficulties ordinarily met in providing stiff seatings do not arise. The result of such an arrangement is to liberate an amount of useful space for additional cargo or accommodation.

Reference has been made to alternating current propulsion, and there appear to be good reasons for preferring this for the majority of normal electrical propulsion schemes. Firstly, its efficiency is high, being over 90 per cent from engine to motor. Secondly, it is a system that lends itself to operation at high rotational speeds, due to the absence of brush gear and commutator difficulties, whereas with direct current it becomes increasingly difficult to deal with big outputs as the speed rises. Thirdly, there is the simplicity with which groups of up to six alternators may be associated with a single motor. With alternating current propulsion it becomes necessary for the engines to have a big range of speed control. They must be able to vary over a speed range from full speed down to approximately one-third of full speed. This means that under all conditions other than maximum output and speed, the engines are running more easily and, of course, compared with the direct current engine with a fixed speed, more efficiently. By grouping as many as four engines onto one motor it is possible to shut down one of the engines and thereby increase the load and economy of the remaining three under many service conditions.

Where it is required to have bridge control with alternating current drive, it is necessary to arrange for remote-controlled servo-operated governors. This can be arranged in a number of ways, the most usual being to employ a series of solenoids which regulate progressively the position of a pilot valve. This valve, in turn, controls hydraulically, by a slave cylinder, the compression of the main governor spring. Alternatively, variable air pressure can be employed in place of solenoids: such an arrangement enables any number of engines to be operated at identical speeds and all to be accelerated or decelerated by a single remote control. At the same time it is, of course, always possible to regulate the speed of any engine independently in the engine room.

A simple and practical system of bridge control that has worked well in service employs the normal mechanical telegraph on the bridge, operating through the usual system of rods to the repeater telegraph in the engine room. This, in turn, is coupled by a dog clutch to the master control, both for the engine governors and the electrical regulators. If at any time it is preferred to employ manual control entirely, it is only necessary to disengage the dog clutch and thereafter regulate the sets in the usual manner. Means are, of course, provided for the independent adjustment of each set. Starting and stopping of the main engines is usually carried out by the engine room staff in response to instructions from the bridge, and the controls thereafter are set and left to the bridge.

In light high-speed craft where the space in the engine room can be extremely restricted, and where there may be a number of engines, it is quite simple to arrange for remote control and starting either electrically or by compressed air. These high-power lightweight engines also have another field in the direct propulsion of the lightweight fast craft that have hitherto been restricted to the use of petrol engines. An interesting example of this is in the machinery now being supplied for a fast yacht, consisting of two 16-cylinder engines each having a maximum rating of 1000 H.P. at 1750 R.P.M. without supercharger. The engines weigh 4 tons each, and the weight of the reversing gear and coupling is 11 hundredweight. The engines are to be mounted on Silentbloc rubber supports, and there is a carden shaft between the engine and the gearbox, which is rigidly bolted to the seatings. The gearbox contains the thrust bearing for both ahead and astern positions. If still further weight reduction is required, the engine can now be constructed in a light alloy. In all instances it is recommended that fresh-water cooling be adopted, but where for any reason this is not considered practicable, sea water can be employed even with the light alloys now available. It is generally preferable, however, to ensure a very rapid circulation of warm water through the jackets of these small engines of high output, and this is most conveniently arranged with a fresh-water system. In the Author's opinion, fresh-water arrangements should be adopted wherever possible in large or small engines, and for high speed or low speed.

Where larger powers are required than can be conveniently arranged with the groups and powers of engines discussed above, then the alternative is, naturally, to adopt a larger cylinder, and here consideration may be given to the larger engine referred to earlier. If built as 12-cylinder or 16-cylinder V type units with a rotational speed of only 750 R.P.M. (1500 feet per minute), and supercharged to give a continuous service rating of 1100 and 1500 H.P. each, such engines would weigh 9 and 12 tons, respectively, and again no flywheels would be required. While these are still relatively compact engines, they cannot be properly referred to as of the high-speed type, but rather fall into the medium-speed category. Their moving parts, such as pistons and connecting rods, are still of a size that can be handled by a man without a crane, and they are so small that no oil cooling of pistons is required. For Admiralty service, engines of this bore and stroke are being supplied for continuous operation at speeds of 900 R.P.M. These larger medium-speed engines naturally require more elaborate installation and seatings than the high-speed type, but even so, for the powers they will develop their installation is extremely simple. These engines are additionally interesting because in certain instances to save weight their frames are fabricated of mild steel plate throughout. While retaining the full rigidity of the cast iron and through bolt frame, the steel frames weigh less than 40 per cent of the cast iron frames. Two engines of the same dimensions but of low speed, arranged to run at 500 R.P.M., with cast iron frames, are being installed in the Clyde vehicular ferry now under construction.

Having now considered the general construction and application of engines of this type, it is proposed to describe briefly the leading design features of the two types.

Dealing first with the design of the 7 by 7¼-inch V engine, it will be seen that this is quite a plain straightforward construction. The crankshaft has a diameter of 4⅛ inches, and for high-speed work is normally constructed in heat-treated nickel chromium steel having a tensile strength of 55 tons per square inch, but for more moderate speeds, of the order of 1000 R.P.M., it may be built in 40-ton steel. The connecting rods are drop forgings of

40-ton steel, one rod being forked where it joins the big-end bearing. The bearing itself is of the normal marine type, but is metalled on the outside as well as the inside so that the connecting rod from the other cylinder of the opposite bank runs against the outer white metal. The motion of this second rod relatively to the first is purely oscillating. The big-end bearing pressure on the pin is 2300 pounds per square inch, without making a deduction for the inertia forces, and this figure compares favorably with the loading of the normal vertical single-line engine. In service these bearings, lined with ordinary white metal, have been immune from cracking or other trouble, and in fact have such an ample margin that on a higher speed development of the same engine running supercharged to a high pressure, it has been found possible to reduce their area.

The main cylinder block and bedplate are straightforward iron castings. The cylinder liners are of the "dry" type, inserted without interference into the cylinder block. These liners, which are only ⅛ inch in thickness, are not themselves in contact with circulating water, and accordingly there are no joints that can leak in any circumstances. By reason of their small size and lightness—each liner in a fully machined condition weighs approximately 10 pounds—they can be made of an extremely high-grade wear-resisting iron, and yet their basic cost compared with the "wet" liner of the 7 by 10-inch engine is only as 1 to 2.5.

The average rate of liner wear on engines of this type and piston speed appears to be of the order of 1½ thousandths of an inch per 1000 hours of running, and since a permissible wear on this bore would be 50 thousandths of an inch, the liners should have a life well exceeding 25,000 hours. Renewal is a matter of extreme simplicity. The pistons are Y alloy castings provided with high-expansion cast iron inserts which carry the top pressure ring. These inserts serve a double purpose; firstly, they resist the hammering and sliding effects of the top ring in its groove, and secondly, they serve to lower the temperature of the top ring materially, As a result, ring wear and ring groove wear are both very much reduced. The high conductivity of the Y alloy results in an extremely low piston temperature, which, in turn, has a beneficial effect upon the lubricating oil, which can be used for long periods without forming heavy sludge.

For very high outputs and speeds—substantially higher than those contemplated in this paper for continuous service—it has been found of benefit to make the rings of taper section. By doing this the top ring is entirely prevented from sticking in its groove, which, in the very great heat, it might have a tendency to do. The fitting of the taper rings differs somewhat from the normal. The ring must be free to "bottom" in the groove before it wedges against the sides, and obviously it must, in that position, be contained completely within the ring groove.

Under these conditions it was found advisable to give a vertical clearance of from 1 to 1½ thousandths of an inch, the angle of taper required being greatest for the highest outputs. In no case in the Author's experience has it been possible to stick a ring having an included angle of 20 degrees.

The cylinder heads are iron castings. Each cylinder is provided with a normal pair of inlet and exhaust valves, the inlet valves being considerably larger than the exhaust in order to permit of the highest volumetric efficiency. The valves are of alloy steel stellited on the seats and operate against stellited inserts. The life of these parts without grinding appears to be almost infinite. After 4000 hours continuous service without any grinding or attention whatever, both valve seat and insert have a bright and unpitted appearance, whereas under comparable conditions unstellited valves would require grinding about every 800 or 1000 hours.

The V engine itself has a high mechanical efficiency due to the single camshaft and crankshaft and to the absence of a flywheel. The construction as a whole has been arranged to give the greatest accessibility to all the parts. Large doors are provided at both sides of the cylinder block beneath the cylinder barrels, and through these doors pistons and connecting rods are inserted and removed. This means that they can be inspected or cleaned without having to remove the cylinder head or even to drain the jackets. The operation of removing a pair of pistons takes under half an hour and, of course, no outside equipment at all, such as handling gear, is necessary. The whole of the valve gear and, in fact, all parts of the engine, are pressure lubricated, and the usual means for the adjustment of tappets are provided. Everything that can conduce to long continuous operation without attention has been incorporated. The larger engines are normally built as vertical straight engines, and embrace many of the features described in the V type of similar size. Provision is made again for the fitting and removal of the pistons through doors in the crank chamber. The advantages of this feature in service have been very marked, and have been appreciated by all who have had to work or operate the engines. The secondary important advantage arising from these big doors is the ease with which access may be had to the crankshaft and its bearings.

The cylinder heads of the larger engines are cast singly, with wet liners of the normal type; otherwise in almost all details the general construction follows similar lines to that described above. When the pistons are being removed or replaced, they are lowered by hand by the aid of a hair pin placed across the crank webs, and from there are slid out through the doors. The weight of the complete piston and rod of the 7 by 10-inch engine is 57 pounds and of the 9½ by 12 inch engine 156 pounds, and the parts are, therefore, readily handled without lifting gear. The straight vertical engines of 7-inch bore, but of 10-inch stroke, are a modification of an earlier series of substantially the same bore and stroke, and due to their earler design the cylinder centers are greater than in the V engine. They are provided with independent cylinder heads and wet liners, but otherwise the main features are similar to those of the V engine. Four engines of the earlier series of this size, each having 8 cylinders, running at 800 R.P.M., were installed in 1934, as the propelling machinery of the Diesel-electric ferries at Queensferry, and their original liners and pistons are still, of course, in service. Similar engines, but having 6 cylinders running at 1000 R.P.M., form the main drive, through reduction gearing, of the *Pomeroon* and her sister ship, *Lady Northcote.*

The limiting feature of the earlier engines was the injection, and it was only the adoption of the system described earlier that has permitted such a big advance to be made in rotational speeds and outputs. As a matter of interest it may be stated that the weight of the 8-cylinder vertical 7 by 10-inch engines is 5¼ tons, including flywheel, while the weight of the comparable 8-cylinder 7 by 7¾-inch V engine is 2¼ tons. In general construction this series of engines is entirely orthodox. As stated previously, they are capable of being run continuously at speeds up to 900 R.P.M., but due to the rising frictional losses, fuel consumption falls as the speed rises above 650 R.P.M.

Conclusion. In referring in detail to some of the similar points associated with the design of medium-speed and high-speed engines for marine service, the Author has endeavored to show that adequate means are available today not only to reduce wear and tear at high speeds and outputs, but also that when attention is required by the high-speed marine type, it can in fact be more readily and easily serviced than the larger lower-speed engines. At the same time, it is hoped to make clear the point that with the exception of a

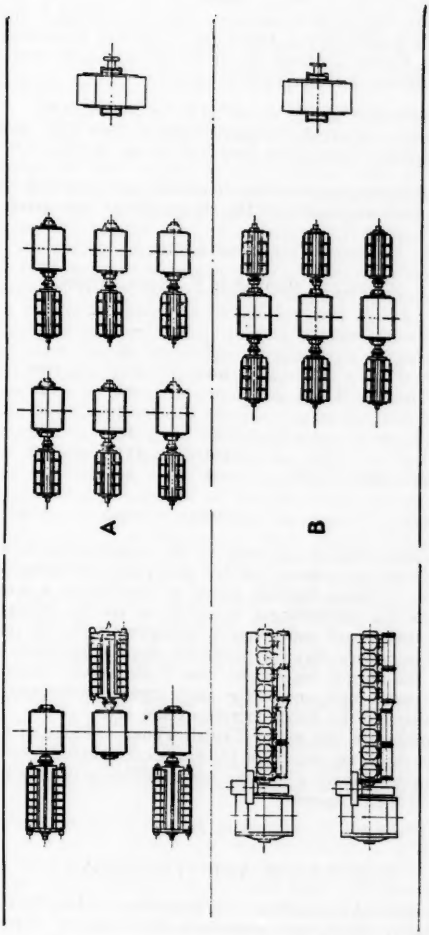

FIGURE 1.

very few individual features, such as pistons and valves, cylinder liners, and possibly the crankshaft, only the normal materials used in the ordinary low-speed engines need be employed.

In "The Motor Ship," * a comparison was recently made of Diesel-electric and direct Diesel machinery with a power of 10,000 S.H.P. In the Diesel-electric drive four engines were proposed, each of 2650 H.P. at 250 R.P.M. As a guide to the possibilities of larger power high or medium-speed engines for this service, Figure 1 shows in outline proposals for the same power with three alternatives for the engines, namely:

A. 6 engine/alternator groups of 900 H.P. at 1250 R.P.M.
B. 3 tandem engine/alternator/engine groups of 1800 H.P. at 1250 R.P.M.
C. 3 engine/alternator groups of 1800 H.P. at 800 R.P.M.

The weights of the engines and the alternators under each of these schemes, and also under that proposed in "The Motor Ship" are given in Table I.

TABLE I.

WEIGHT OF 10,000 S.H.P. INSTALLATION.

	A tons	*B* tons	*C* tons	*"The Motor Ship"* tons
Engine	46	46	72	350
Alternator	76	50	62	63
Switch gear	22	18	18	20
Total	144	114	152	433
Propelling motors, 250 R.P.M.	34	34	34	120 (100 R.P.M.)
Overall efficiency	90.5	90.5	91.6	

The efficiencies given include all losses in the propelling motors, alternators, motor-driven exciters, excitation, and fan power for ventilation, etc. At sea, auxiliary service, including lighting, would be supplied by a constant voltage exciter set, while the supercharger would be driven by alternating current motors, so that their speed and power requirements fell with reduced engine speed. In port, auxiliary services would be supplied by direct current generating sets of the normal high-speed type if the power requirements were low, but if they were high, one of the main engine groups could be used to provide power through the direct current exciter set.

Acknowledgments are due to the British Thomson-Houston Co., Ltd., for their courtesy in supplying details of the electrical equipment referred to, and also to many engine makers who have loaned slides or supplied photographs and particulars of their engines.

BERYLLIUM AND ITS ALLOYS.

Recently, the physical properties of various alloys of beryllium, particularly the beryllium-copper alloys, have awakened much interest. These properties are discussed in "The Metallurgist," supplement to "The Engineer," London, England, of August 26, 1938.

* "Motor Ship," 1938, vol. 18, p. 388.

Some time ago the publication by W. Hessenbruch of a survey of the properties of beryllium and its alloys was the occasion of a brief summary of information on the subject in the pages of this journal,[1] and a further paper by the same author[2] suggests the desirability of bringing the matter up to date by a similar review, including references to other recent publications on the same subject which are interpolated in the following account of Hessenbruch's paper. One such publication is the paper by C. B. Sawyer and B. R. Kjellgren,[3] contributed to the American Chemical Society's symposium on "Less Familiar Elements," held in Cleveland, Ohio, on December 27th to 29th, 1937. This deals specially with American developments.

Hessenbruch,[2] after mentioning the special difficulties introduced into the electrolytic separation of beryllium by the need of operating at the unusually high temperature of 1400 degrees C. (the melting point of beryllium being 1280 degrees C.), refers to a recent process[4] in which chloride baths are electrolyzed below the melting point of beryllium, yielding spangles of the metal containing 99.0 to 99.5 per cent beryllium. The metal cannot be used in this form for making alloys unless special precautions are taken against oxidation. It may, however, be remelted in hydrogen or *in vacuo* and compact masses of beryllium (cubes, discs, cylinders, or short tubes) can be prepared. These have a density of 1.86 and a Brinell hardness of 150. They cannot be worked and both on account of their relative brittleness and high price they have no application, except for the use of thin discs as windows in electric vacuum discharge tubes, since their transmission of α and γ rays is very high compared with that of aluminium. Sawyer and Kjellgren name no actual use of metallic beryllium, but call attention to its possible acoustic applications on account of the very great velocity of sound in the metal (more than 2¼ times the velocity of sound in steel), dependent on its low density and high modulus of elasticity, *viz.*, 19,000 tons per square inch. This is a calculated figure, but it is confirmed by the fact that the 84 per cent beryllium-aluminium alloy has a measured modulus of about 16,500 tons per square inch, *i.e.*, about 24 per cent higher than that of steel. Absence of ductility militates against the use of beryllium-rich alloys. For a sand-cast alloy containing 67.4 per cent of beryllium and 30.5 per cent of aluminium which had been suggested for the manufacture of pistons for aircraft engines, Johnson[5] found a Brinell hardness of 75, a maximum stress of 6.2 tons per square inch (probably low on account of premature failure, owing to brittleness), no elongation, and a thermal conductivity about half that of a silicon-aluminium alloy.

The production of ductile beryllium seems to be no nearer to achievement. By distillation of 99.8 per cent beryllium at 1400 degrees C. *in vacuo* in beryllia-lined vessels, Kroll[6] obtained a product of 99.95 per cent purity, which had a Brinell hardness of 110 and was to some extent malleable when hot, but he concluded that cold brittleness appeared to be a physical property of the element.

With reference to the method of production of the metal referred to by Hessenbruch, it may be stated that electro-deposition of beryllium below its melting point is not new; the work of Sloman and of Fischer and Schwan in this direction was described several years ago.[7] In view of the main use of beryllium the direct production of a copper alloy is probably of more practical interest. Fink and Shen[8] recently described an electrolytic method in which molten copper served as cathode in a fused bath containing beryllium oxyfluoride with sodium and barium fluorides; and Hessenbruch states that the Heraeus-Vacuum-Schmelze A.G. are now able to make beryllium-copper directly by thermal reduction of beryllia in the presence of copper.

BERYLLIUM-COPPER ALLOYS.

By far the greater part of the beryllium obtained today goes into copper alloys, the so-called beryllium bronzes. When the beryllium exceeds 1 per cent, they are susceptible to hardening by quenching and reheating. In the quenched condition they may be cold worked, and the subsequent treatment at about 300 degrees C. not only removes residual stresses, but also causes precipitation hardening. The properties of these alloys are given in Table I. It is claimed[2] that on account of the strong affinity of beryllium for oxygen, nitrogen, sulphur, and other non-metallic elements, melting these alloys *in vacuo* is of the greatest importance, and examples are given of the excellent ductility of the vacuum-melted alloys. The outstanding use of beryllium bronze is for springs. It possesses advantages over phosphor bronze in having, with a somewhat higher yield point, almost double the fatigue limit in alternating torsion (Table II), and it may be used in circumstances in which the performance of phosphor bronze springs is inadequate, and steel springs are not sufficiently resistant to corrosion. A study of the corrosion of beryllium-copper alloys by Terem,[9] both by loss of weight and by surface

TABLE II.—*Properties of 4 mm. Diameter Wire for Springs.*[2]

Material.	Yield point in tension.	Torsional fatigue limit.	Modulus of rigidity.
	Tons per square inch.		
Phosphor-bronze, spring hard, unpolished	17·8	±6·3	2860
Beryllium-bronze, 2·5 per cent. Be, quenched, work hardened and treated, unpolished	23·5	±10·8	2860
Ditto, polished	19·0	±12·0	3050

examination, showed that their resistance to sea water was good, and that they suffered little attack in dilute hydrochloric and acetic acids. In sulphuric and nitric acids, caustic soda and ammonia, the attack was considerable. In tests carried out in the rotating beam machine, Gough and Sopwith[10] found that there was no diminution in the endurance of beryllium bronze in salt spray. The corrosion fatigue limit, both of phosphor bronze and of beryllium bronze, was as high under these conditions as in air, but phosphor bronze had not so great an endurance limit to start with, *viz.*, 9.8 as against 16.3 tons per square inch. In corrosion fatigue resistance, beryllium bronze was superior to the best stainless steels investigated by them.

The resistance to oxidation of beryllium-copper alloys has also been studied by H. N. Terem[9] in experiments in which alloys containing up to 10 per cent of beryllium have been heated at temperatures between 610 and 910 degrees C. Small quantities of beryllium considerably reduced the rate of oxidation of copper. A minimum rate was reached with 2 per cent of beryllium. This alloy gave the same rate of oxidation as stainless steel at 810 degrees C. though at lower temperatures it was oxidized more rapidly than the steel. The behavior was very dependent on the physical condition of the alloy; powder alloys on account of their fine state of division oxidized rapidly.

TABLE I.—Pr

Alloy.	Condition.	Brinell hardness number.	Yield tons sq. i
Be-Cu (α) 1% Be, Sp. gr. 8·6	Quenched	65–70	9
	Quenched and heat treated	125–130	25
	Quenched and work hardened	200	45
	Quenched, work hardened, and heat treated	230–240	41
Be-Cu (α) 2% Be, Sp. gr. 8·3	Quenched	100–120	17
	Quenched and heat treated	330–360	63
	Quenched and work hardened	220	51
	Quenched, work hardened, and heat treated	365	66
Be–Cu (α+β) 2·4% Be, Sp. gr. 8·2	Quenched	110–130	21
	Quenched and heat treated	340–370	66
	Quenched and work hardened	230	57
	Quenched, work hardened, and heat treated	375	71
Co-Be-Cu (α), 2·6% Co, 0·4% Be, Sp. gr. 8·8	Quenched	75–80	9
	Quenched and heat treated	185–200	31
	Quenched and work hardened	150	33
	Quenched, work hardened, and heat treated	210	36
Be-Al-Si-Cu (α+β) Sp. gr. 8·0	Quenched	170	28
	Quenched and heat treated	300	57
	Quenched and work hardened	220	52
	Quenched, work hardened, and heat treated	320	63

TABLE III.—

Alloy.	Condition.	Brin hard numb
Be-Ni, 2% Be, Sp. gr. 8·1	Quenched	14
	Quenched and heat treated	42
	Quenched and work hardened	36
	Quenched, work hardened, and heat treated	48
Be-Ti-Ni, Sp. gr. 8·1	Quenched	15
	Quenched and heat treated	44
	Quenched and work hardened	36
	Quenched, work hardened, and heat treated	50
Beryllium-contracid, * Sp. gr. 8·3	Quenched	19
	Quenched and heat treated	32
	Quenched and work hardened	30
	Quenched, work hardened, and heat treated	45

* Contracid is an alloy containing ni

NOTE.—Much of this information has been available for a long time,[1] but ad
with the tensile strengths reported.

TABLE I.—*Properties of Beryllium-Copper Alloys.*[2]

ell ess er.	Yield point, tons per sq. inch.	Maximum stress, tons per sq. in.	Elongation, per cent. $l = 10\,d$.	Reduction of area, per cent.	Impact value, mkg. per sq. cm.	Elastic modulus, tons per sq. in.	Electrical conductivity, per cent. of El. Cu.	Coefficient of expansion, 20–200 deg. $\times 10^{-6}$.
70	9·5	19·0–22·2	50–55	85–90	13	—	25	—
130	25·4	28·6–31·7	30–35	80–85	18	6120	28	17·8
)	45·7	47·6	6	70	15	—	25	—
240	41·3	54·0	12	55	10–12	7000	30	17·7
130	17·8	31·7–33·0	60–62	75	15	—	17·5	—
360	63·5	69·8–76·2	3–4	12·5	1·5	6650	33	16·9
)	51·4	54·0	6	45	8	—	16·5	—
5	66·6	70·4	5	15	1·5	7600	25–35	17·1
130	21·0	36·2–39·4	30–35	35–40	10–11	7500	17	—
370	66·6	76·2–82·5	3–5	11	1·3	8250	30	17·3
)	57·8	60·3	3	25	3·5	7600	16	—
5	71·2	85·7	4	45	1·3	8250	20–30	17·2
30	9·5	19·0–22·2	30–35	65–80	11	—	27	—
290	31·7	38·1	15–16	35–38	7	7000	38	17·8
)	33·6	34·9	6	50	8	—	24	—
)	36·8	47·6	15	45	7	7300	40	17·6
)	28·6	47·6	15–20	15–20	2–4	—	9	—
)	57·2	66·6–73·0	2–3	5–8	1–2	8900	10	18·5
)	52·7	54·0–60·3	1–2	5–10	0·5–1	—	8	—
)	63·5	73·0–79·3	1·5–2·5	10–15	1	8900	9·5	18·1

TABLE III.—*Properties of Beryllium-nickel Alloys.*[3]

	Brinell hardness number.	Yield point, tons per sq. in.	Maximum stress, tons per sq. in.	Elongation, per cent. on 10 cm.	Impact value, mkg. per sq. cm.	Elastic modulus, tons per sq. in.	Electrical resistivity, microhm-mm.	Coefficient of expansion, 20–200 deg. $\times 10^{-6}$.
...	140	22·8	50·8	48	7·1	11,120	0·34	—
...	420	50·8	82·5	20	4·0	11,630	0·21	—
...	360	95·3	101·6	1·5	4·6	11,430	0·32	—
...	480	95·3	117·5	8	4·5	12,080	0·19	13·9
...	150	25·4	54·0	40	—	—	0·35	—
...	440	50·8	88·9	1·5	—	13,300	0·24	14·9
...	360	98·5	104·5	1	—	—	0·36	—
...	500	98·5	120·5	5	—	13,650	0·29	14·8
...	195	26·5	55·9	30	13·9	9,850	1·20	—
...	320	31·5	63·5	23	8·1	10,230	1·23	—
...	350	89·0	95·3	2	3·3	10,730	1·03	—
...	450	95·3	117·5	6	2·8	11,760	1·08	13·9

ontaining nickel 60, chromium 15, molybdenum 7 per cent., remainder iron.

ime,[1] but additional data are also given. The Brinell hardness numbers do not always appear to be consistent

In addition to its use for springs, beryllium bronze has a sale as non-sparking safety tools for chemical and explosive factories. It is evident, though not always borne in mind in chemical and oil works, that sparks may be produced by non-sparking tools if the material worked can itself give sparks.[11] Toothed gear wheels are also made of beryllium bronze on account of the high resistance to wear of the hardened alloys; the forged material has a considerably longer life than cast gears. The precipitation which increases the hardness of the alloy simultaneously reduces its electrical resistivity. For this reason certain types of beryllium bronze have proved useful as electrodes in automatic electric welding machines. The properties of one such "conductivity" bronze containing cobalt are shown in Table I.

The binary beryllium-copper alloys will not harden unless the beryllium is at least 1 per cent. There has been a considerable amount of investigation directed towards the development of alloys containing additions, such as cobalt, chromium, and nickel, which render heat treatment effective even when the beryllium content is low. This has led in America to the production of the General Electric Company's "Trodalloy," No. 1, a copper alloy containing 2.6 per cent of cobalt and 0.4 per cent of beryllium, and No. 2, with 0.4 per cent of chromium and 0.1 per cent of beryllium.

Their properties have been investigated in detail by Harrington,[12] and have also been described by Fuller.[13] No. 1, after water quenching from 900 degrees C. and reheating for one hour at 500 degrees, has a tensile strength of about 40 tons per square inch, with an elongation of 10 per cent and an electrical conductivity about 40 per cent of that of copper. The alloy is said to have good spring properties up to 400 degrees C. The No. 2 alloy, quenched from 925 degrees C. and reheated to 500 degrees C., has a much higher conductivity (73 per cent of that of copper), but its tensile strength is only a little over half that of alloy No. 1. Alloys of this kind are also being developed in Japan by Sumitomo Metal Industries, Ltd. Inamura and Ohashi[14] have described the properties of "Berychrome No. 1," a copper alloy containing nickel 2, chromium 0.5, and beryllium 0.5 per cent, which is slightly inferior in mechanical properties, but superior in conductivity to ordinary beryllium bronze. In Russia also Amsterdamski[15] has published a series of papers in "Metallurgy" on the influence of various additions on the mechanical properties of beryllium-copper alloys. These alloys have also formed the subject matter of several researches[16] dealing with the mechanism of age hardening.

BERYLLIUM-NICKEL ALLOYS.

To return now to the contents of Hessenbruch's paper, the properties of three technical nickel alloys are given in Table III, the binary alloy with about 2 per cent of nickel, a more complex alloy of nickel with beryllium and titanium, and the alloy of nickel with chromium, molybdenum, iron and beryllium, known as beryllium contracid. All these have good resistance to corrosion, and also to oxidation up to 700 degrees C. or 1100 degrees C. in the case of beryllium contracid. They may be utilized for high-duty springs, and the durability of a sharp edge or point in the hardened alloys makes them suitable for scalpels, surgical needles and, in the form of seamless tubes, for hypodermic needles. Laissus,[17] in continuation of his numerous experiments on the cementation of metals by various elements, including beryllium, has found that nickel heated in contact with a 3 : 1 mixture by volume of 80 per cent ferro-beryllium and beryllia for ten hours at 1150 degrees C. absorbs beryllium to a depth of 4 millimeters (ten times as great a depth as at 1100 degrees C.), the Brinell hardness of the surface being increased from

82 to 568 without further treatment after cementation. Though it is claimed that the process is capable of industrial application, no instance is known of the practical use of surfaces cemented with beryllium.

BERYLLIUM-IRON ALLOYS.

At present the binary alloys of iron and beryllium have no technical interest. Though they are susceptible to precipitation hardening, they are coarse grained and brittle. In the quenched condition the hardness increases from about 150 to 480 as the beryllium rises from 0.5 to 9 per cent. After reheating it rises from 150 to 700 with increase of beryllium from 0.5 to 5 per cent, and then remains constant. All practical applications of beryllium to ferrous alloys concern the austenitic steels, especially the high nickel steels of low coefficient of expansion. The application of these alloys for hair-springs dates back several years.[1] The alloy with 36 per cent of nickel, 1 per cent of beryllium and the rest iron has a Brinell hardness of 180 as quenched, 360 when hardened, and over 400 when cold work is applied before the final treatment. The coefficient of expansion of the 36 per cent alloy is increased by the addition of beryllium, but the rise can be minimized by increasing the nickel 38 per cent. As a further possibility, Hessenbruch refers to a beryllium-containing tool steel in which the temper hardening effect of beryllium is superimposed on the quench hardness of carbon steel, but no details are given, as the necessary development work is not yet concluded.

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SPECTROSCOPY IN INDUSTRY.

The inspection of materials is a matter of concern in many fields of engineering. Spectroscopy offers one method of non-destructive testing as well as a means for rapid determination of ingredients in connection with several processes. The following paper was presented by George R. Harrison, Ph.D., at a meeting of the Franklin Institute of Philadelphia, Pa., then printed in the July, 1938, issue of the Journal of that Society.

The spectroscope, long recognized as one of the most powerful tools of scientific investigation, has been used during the past forty years to obtain information which has revolutionized physics, chemistry, and astronomoy, and greatly affected biology, metallurgy, and medicine. Since many modern industries rest on scientific discoveries in these fields, it would be surprising if the spectroscope were not found useful in connection with technological processes. So rapidly, in fact, are spectroscopic methods now being adopted by industrial laboratories, that most manufacturers of spectroscopic equipment are having difficulty in keeping up with orders for their instruments, and some are even beginning to worry about the availability of such raw materials as crystal quartz, needed for prisms and other optical parts. Spectroscopic methods have been found particularly valuable in the metals industries, in those industries which involve the canning and packaging of foods, and in all other industries which use materials whose purity must be carefully determined and controlled.

The spectroscope has served the physicist and the astronomer as a telescope, a microscope, a speedometer, a thermometer, a tape measure, and a clock, in addition to its more usual functions, and in each role it has exceeded in range and power the more common forms of these devices. Today in industry its greatest usefulness is found in applications which supplement chemical wet methods of qualitative and quantitative analysis, and with its aid our ability to detect and measure small quantities of material has been extended very greatly.

As has often been pointed out, a teaspoonful of salt cannot hide from a spectroscope in a swimming-pool full of water. Though far less gold than would repay concentration is found in sea water, the spectroscope has no difficulty in detecting the small amount which is there. Such sensitivity might appear excessive for industrial purposes, where ability to detect a trace of almost any element in any given sample would seem valueless if nothing could be done about its presence. Fortunately, something usually can be done. Though in many cases the properties of metals are greatly influenced by traces of impurities too minute to be eliminated conveniently by ordinary methods of purification, addition of minute quantities of other impurities will often offset undesired characteristics. In the case of fusible alloys for safety valves or fire sprinklers, for example, certain impurities if present by as much as one part in ten thousand will raise the melting point by undesirable amounts. A relatively small number of atoms in the crystal boundaries can produce a marked effect, but atoms of other materials which will depress the melting point again to its proper value can be added. The spectroscope is invaluable in determining which impurities are responble for such effects, and which elements must be added to offset them.

The outstanding value of the spectrograph comes in qualitative analysis. Let us watch two scientists looking at a tiny piece of lamp filament. To all outward appearances it is exactly the same as any other piece of filament, but in an incandescent lamp it was found to last twice as long as did filaments made from ordinary wire. There is not enough material to analyze chemically, for the sample is small and no advance hint tells what to look for. A

chemist using ordinary methods would be forced to guess as to which elements were most probably present, and eliminate them one after another. Long before he was finished such a small sample would probably be exhausted. But here is a spectrograph; the operator loads it with a photographic plate, opens the shutter, and inserts a tiny piece of the filament into an electric arc placed in front of the instrument. There is a flash of colored light and the spectrum is recorded. Shifting the plate the operator repeats the process, the second time burning a piece of an ordinary filament. When he develops the spectrogram the story stands completely revealed. Each type of atom in each filament has sent out its own group of waves of different lengths, and produced its own pattern of spectrum lines. By looking for differences in these patterns, and identifying the elements from which the various lines which differ are known to originate, the spectroscopist can see quickly and accurately which elements are present in one filament and not in the other.

The pattern of lines on a spectrum photograph may look complicated and meaningless to the layman, but to the experienced spectroscopist it often tells a story as definite as that told by a line of printing. This was perhaps not realized by the advertising agents of a manufacturer of motor cars who recently strove to impress the American public with the scientific methods used in his factory, by printing in some of the leading weeklies full page advertisements which pictured a laboratory worker gazing at a spectrogram, with the caption "Eyes That See Through Steel." The description which followed of the value of the spectroscope in perfecting automobile parts was a very good one, but every line in the spectrum at which the man was looking quite obviously had come from zinc atoms!

Spectroscopic analysis indicates that no entirely pure sample of any metal has ever been prepared, and since single foreign atoms placed here and there in the lattice structure of a metallic crystal can greatly affect its properties, really pure metals probably have properties with which as yet we are not familiar.

In the food preserving industries the spectrograph is coming into very wide application. That two or three parts of aluminum or lead can be detected readily in ten million parts of lobster or condensed milk may seem unimporant, since such concentrations are below the toxic limits considered dangerous to health, yet obviously tests on the rapidity with which the internal coatings of cans dissolve in foods stored within them can be made more easily and quickly when such sensitive methods of detection are available. Chocolate and chewing gum manufacturers use spectroscopic analysis to insure that the lead content of their products is below the limits set by pure food laws. Whiskey distillers, finding something in their product which causes it to turn cloudy, have used the spectrograph to locate the cause in minute amounts of cadmium, let us say, (to cloak the real offender in anonymity); and by analyzing samples from various parts of the distillery line, have been enabled to locate the coil or condenser which introduced the offending element.

Has the arsenic and lead been properly removed from sprayed fruits before canning? The spectrograph will tell. Is beer kept in cans dissolving anything more from the container than it would if kept in bottles? Again, the spectrograph gives an easy means of deciding.

Spectroscopic analyses can be performed by two entirely independent and dissimilar means which have different applications. In emission analysis, use is made of the characteristic light emitted when the material is burned electrically in front of the slit of a spectrograph. In the second method, absorption spectrophotometry, light waves of every length in the desired region are sent through the material to be analyzed (which must be somewhat transparent, like glass or blood serum or peppermint extract or beer) and the

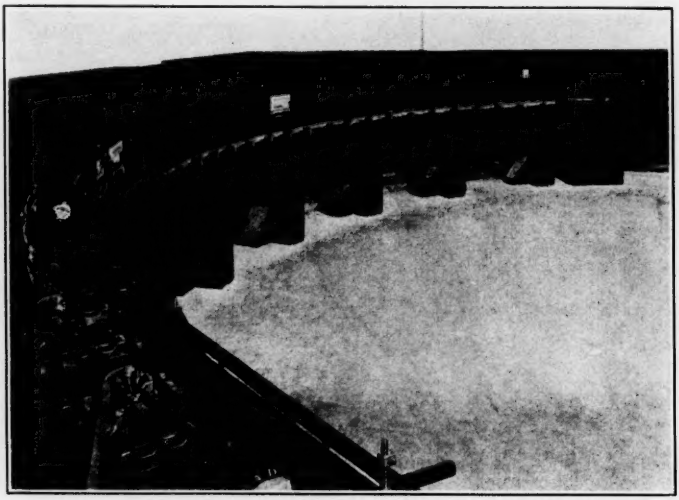

FIGURE 1.—SECTION OF A LARGE CONCAVE GRATING SPECTROGRAPH AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY, WHICH COVERS OVER 1200 SQUARE FEET OF FLOOR SPACE. THE SPECTRUM LINES ARE PHOTOGRAPHED WITH HIGH PRECISION ON FORTY FEET OF PHOTOGRAPHIC PLATES CLAMPED TO THE TRACKS SHOWN.

spectrograph is used to determine how much of the light of each wavelength has been absorbed by the material.

By the first method, seventy of the chemical elements can readily be detected and measured. The permanent gases, carbon, and a few other nonmetallic elements produce few lines in the spectral regions commonly photographed, and since almost all molecules are dissociated in the arc into their constituent atoms, organic materials are burned away without appearing in the analysis. When an apple or a cranberry is ashed in an electric arc, for example, the strongest lines which appear in the spectrum are those due to such elements as sodium and copper and iron.

When one is interested in molecules the second method of spectrographic analysis can be used. Though its application is limited to materials which are somewhat transparent, it has the advantage of not affecting the material which is being analyzed, since this is merely penetrated by a beam of light.

The modern spectroscope is not the small brass tube standing on a tripod so familiar to chemistry students, who have used it to observe the colored lines produced by different salts when burned in a flame. One of the research instruments used for precise work may fill a room forty feet square (as shown in Figure 1), and several laboratories contain more than a dozen different types of spectrographs. For industrial work three main types are in most common use. The quartz prism instrument of medium size, which records on one plate the spectrum between the limits 5000 Angstroms and 2000 Angstroms, is useful for absorption spectrophotometry, since the absorption bands of solids or liquids are usually so wide that great separation of the waves of different lengths is valueless. This instrument can also be used for emission analysis where the substances being studied have fairly simple spectra, such as the alkalies and alkaline earths, and in general those atoms which lie on the left-hand side of the Periodic Table. Iron and most other atoms of the long periods have such complex spectra that greater resolution of the lines is required, and a large quartz instrument of the Littrow type is most commonly used. This records in three settings the part of the spectrum most important for analytical purposes, lying between 2000 Angstroms and 5000 Angstroms, when a quartz prism is used, and a glass prism can be substituted with which the visible spectrum can also be recorded.

The concave diffraction grating spectrograph has long been considered one of the more convenient types of spectrograph in research laboratories, and this instrument is now slowly making its way into industrial use. It has the advantage that it can be used with light waves of any length from the long infra-red to the shortest ultraviolet, a single instrument covering all the the desired ranges without change of optical parts. Again, the grating produces almost uniform dispersion from the shortest to the longest wavelengths, whereas the dispersion of a prism decreases rapidly toward longer wave-lengths, which makes identification of the lines easier and uses the photographic plate more effectively. The new aluminum gratings on glass, ruled by R. W. Wood at Johns Hopkins, have done much to remove prejudice against the grating because of the comparatively low intensity of the spectra it produces. Several of Wood's gratings produce spectra more intense than those produced by prisms, and with such a grating exposures in which thousands of lines from an iron arc are recorded in five seconds are not uncommon.

Some industrial users of spectrographs who express great satisfaction with their prism instruments consider the grating spectrograph too fragile for use in their laboratories. This speaks well for the prism type of instrument, but usually bespeaks lack of familiarity with the grating. Where good prism and grating instruments are both available the grating instrument is commonly the favorite, and that it cannot be the delicate apparatus

sometimes supposed is borne out by its very satisfactory use in such metallurgical laboratories as those of the Watertown Arsenal and the Cleveland Lamp Works.

As a typical example of all-around use of the spectrograph in attacking an industrial problem, I shall discuss the spectroscopic procedure connected with what we may call "The Case of the Hafnium Crystals." (The real crystals were not hafnium, nor were they, in fact, crystals.) The spectroscopic procedure used was so varied that the case serves as an excellent illustration. The problem was to locate minute deposits of hafnium in a certain transparent crystalline material, and to measure the distribution and amount of the hafnium in typical crystals. The spectrographic method was selected as one of the best ways of doing this.

First, emission analysis was used to determine the amount of hafnium present in the crystal material. Several milligrams of the material were burned in an electric arc, and the light emitted was photographed with a spectrograph. The wave-lengths of all lines appearing on the plate were then determined with an accurate measuring engine, and from published catalogs of wave-lengths all lines appearing on the plate were assigned to their parent atoms. A qualitative analysis of all metallic elements present in amounts greater than about one part in a million was thus obtained.

A spectrographic quantitative analysis was next made. From the qualitative analysis the elements could be grouped into three classes by observing the intensities of their spectrum lines. Those which were present in large concentrations (above about 1 per cent) were listed as major constituents, those present in amounts lying between 1 and 0.001 per cent were listed as minor constituents, and those present in smaller amounts as traces.

In general, one may say that for major constituents, spectroscopic methods of quantitative analysis are slightly inferior in precision to chemical wet methods, for minor constituents they are equal in precision, and for traces they are superior, assuming sufficiently large samples are available to make adequate chemical analyses. Spectroscopic methods have their greatest advantage when the samples available are small, or concentrations are low, because the precision of the spectroscopic method stays sensibly constant at all concentrations. With it one can distinguish as readily between 0.0010 and 0.0011 per cent concentration of material as between 10 and 11 per cent, for example.

The concentration of a minor constituent is determined by observation of the intensities of its spectrum lines relative to those of the matrix material (which is composed of the major constituents), and as these ratios vary with a number of factors, a null method must be used. Standard comparison samples are made up which differ from the sample to be measured only in regard to the constituent being measured, and these samples and this unknown are burned and photographed in identical manner. Then, if the intensities of the lines of the constituent in question are the same in any comparison sample as in the unknown sample, the concentration of the constituent will be the same in the two samples.

Such rigid conditions might seem impossible to fulfill, but fortunately any number of minor constituents and traces may differ in the known and unknown samples without affecting the result. If we are comparing the copper content of two bronzes, for example, error may result if lead be present in one sample in amounts greater than 1 per cent, and not in the other, but in amounts less than about 1 per cent a difference in lead content should not affect the results appreciably.

Returning to the crystal problem, having made up a series of samples of the material containing various known concentrations of hafnium covering

the range suggested by the qualitative analysis, we now burn these in the arc in succession, sandwiched between alternate exposures burning the unknown sample. When the plate has been developed, fixed, and dried, we can measure the amount of blackening of each of the hafnium lines on a microdensitometer, and plot a "working curve" of density against concentration. Or, as is more common, by calibrating the plates we can change densities into the actual line intensities to which they correspond, and plot intensity against $\log_{10}$ concentration. At low concentrations such a plot is usually a straight line which aids greatly in interpolating between two standard intensities. By this means, using care, precision to 3 per cent can usually be obtained, which at concentrations below 0.1 per cent is ordinarily greater than that of chemical methods.

Having determined the actual amount of hafnium present, we are now ready to determine its location in the crystals. The first method tried was to pick out small particles of the crystal and burn them in the arc, observing visually the intensities of the visible hafnium lines with a spectroscope. A sample the size of a pinhead was found to give fairly consistent results, but particles less than 1 millimeter in diameter were too likely to be lost from the arc. A series of runs was made to determine the minimum amount of hafnium which could be detected spectroscopically. A weighed sample of the material, known to contain 10^{-5} grams of hafnium, was introduced into a 2-ampere arc between pure graphite electrodes. Strong hafnium lines were found to be still visible in the spectroscope after 1000 seconds of burning. The spectrum was then photographed with a high-speed spectrograph, and an exposure of 0.0001 seconds was found sufficient to record the lines. This indicates that no more than 10^{-12} grams of hafnium were required for spectrographic detection, but actually the efficiency of excitation of the hafnium atoms is much greater under these conditions than under conditions in which only the minimum detectable amount of material is introduced into the arc. 10^{-8} grams can usually be detected without difficulty, however.

Emission methods were thus shown to be insufficiently sensitive for the problem at hand. Since the crystals were transparent, the absorption method could be tried, and this method was found satisfactory. Ultimately amounts down to 10^{-16} grams of hafnium were successfully located in the crystals by absorption methods.

The first step in this new attack was to determine the absorption spectrum of hafnium salts of the type present in the crystal. The hafnium-containing crystalline material was dissolved in water, and a quartz vessel filled with the resulting solution was placed between the light source (a hydrogen discharge tube, which gives a good continuous spectrum in the ultraviolet) and the slit of the spectrograph. On the same plate an absorption spectrogram was taken of similar crystal material which contained no hafnium. The differences in absorption were obviously due to the hafnium salt, which was found to absorb strongly in the ultraviolet, a little in the violet, and practically not at all in the visible region.

The final step was to locate spots in the crystals which showed this characteristic absorption. For this purpose a spectrograph and an ultraviolet-transmitting microscope were combined. Sections of the crystal were thus photographed in each individual line of the mercury spectrum from a quartz mercury arc. Thus the crystal was photographed under high magnification in transmitted monochromatic green light, in blue light, in violet light, and in the light of several ultraviolet lines.

Opaque materials in the crystal showed dark in all these photographs. Transparent materials which were not hafnium showed light in all. The hafnium

salts showed transparent in green and blue light, darker in the violet light, and opaque in the ultraviolet. Thus any particle which showed this progressive absorption could definitely be called a hafnium carrier, and from its opacity its hafnium concentration could be determined.

This method was then further simplified by using a microscope adapted to either visible or ultraviolet light, and taking duplicate photographs of each crystalline particle, immersed in an oil of the proper index of refraction, first with green light, and then with ultraviolet light of the desired wavelength. Magnifications up to 2000 diameters could be used, and thus extremely small amounts of hafnium could be located, since a layer of "hafnium" atoms only five atoms thick will give an observable degree of opacity.

Most industrial spectroscopic problems are simpler and more readily solved than the one sketched above, but it is described as illustrating a number of different methods of using a spectrograph.

For many industrial purposes it is important that speed be combined with precision. Two hundred tons of molten copper in a furnace represents a large investment which can be lost through improper treatment. The copper must be removed from the furnace at the proper degree of purification, and several hours may be consumed in determining by chemical methods the proper time for removal. Often recourse is had to rule of thumb methods, for lack of anything better. An ideal solution would be a spectroscopic arrangement such that the furnace operator could periodically dip some molten copper from the furnace, burn it before a spectroscope and decide from the appearance of certain impurity lines exactly when the proper time for removal was reached. There is no fundamental reason why this operation should take more than two minutes if performed visually or with a photoelectric cell.

Eye methods can be used in certain cases only, since many of the important lines for analysis lie in the ultraviolet region. It is, to be sure, possible to use fluorescence to observe ultraviolet lines, but this method has not yet been well developed. It awaits an increased demand from industry, which in turn awaits knowledge of the feasibility of such methods.

The photoelectric method of spectroscopic analysis has been tried with encouraging results in Germany and at the Watertown Arsenal in this country, and shows considerable promise, though it must be considered as in only a preliminary state of development. The limitation on this technic, which is simple and should be capable of precision, is in getting enough light to operate photocells from a single line of an element which is present in the sample in only small amounts, when this line is in the midst of a bewildering array of strong lines from other elements. Spectroscopes of high speed, combined with improved phototubes and amplifiers, and improved sources will probably bring ultimate perfection of this rapid method.

The photographic method can be speeded up greatly, and in at least one foundry, that of the Campbell, Wyant and Cannon Co. of Muskegon, Michigan, most of the routine chemical tests on the output of the foundry have been superseded by rapid spectrographic methods. Quick results are of great importance, and by hastening the processing of the photographic plates used a method has been developed which gives precise quantitative analyses on six elements in a single sample in fifteen minutes or less. As reported by Vincent and Sawyer * spectra for forty-eight analyses on eight samples are recorded on each plate, and the posting of results from a plate can be completed within thirty-five minutes after receipt of the samples. Repeat runs were found to be more consistent from the spectrographic laboratory than

* H. B. Vincent and R. A. Sawyer, "Journal of Applied Physics," March, 1937, p. 163.

from the chemical laboratory for such elements as silicon, molybdenum, chromium, nickel, manganese, and copper.

Such successful utilization of the spectrograph twenty hours a day in a foundry under industrial conditions of stress, with resulting improvement in precision of results, speed, and decrease in cost, emphasizes that the spectrograph is a practical tool.

For rapid testing of raw materials special simple types of spectroscopes have been developed by various manufacturers. A notable example is the Spekker Steeloscope of Adam Hilger, Ltd. This is a small portable fixed prism spectroscope with a movable eyepiece on which are engraved the various important lines of elements which are to be sought after. A technician of moderate skill, who needs only a reasonable amount of special training, can travel from one car to another of a freight train loaded, for example, with pig iron, carrying his spectroscope and dragging behind him a 220-volt cable carrying direct current to run an electric arc. Selecting a sample pig he strikes an arc between this and a rod of pure iron which he carries for the purpose, and observes the light through his spectroscope, with the eyepiece set for "nickel" or whatever element he is interested in. A special eyepiece can be obtained which, by a clever optical arrangement, enables the eye to compare the intensities of two lines. By setting this at some predetermined value the operator is enabled to tell at once whether the nickel content, for example, is within the limits of acceptance, and it is thus but a job of a few hours to sample and analyze a whole trainload of iron without even bothering to unload it.

Such possibilities in industry are almost endless, but since special methods are required for special purposes, their application awaits the demands of industrialists. The first reaction to the spectroscope is usually amazement at its possibilities. Somewhat further investigation then frequently brings a reaction of disappointment, because it will not solve every problem which may be presented. The next reaction is that perhaps matters are not so hopeless after all, since a little special attention to each case may show how to get around the difficulty.

So we see paper manufacturers who want to discover the source of tiny black specks in their product, bakery equipment manufacturers who wonder if their new coating compound for pans is contaminating the dough, spark plug manufacturers who wish to study the effect of minute amounts of alkali metals in improving sparking, metallurgists who wish to trace the origins of ores, all trying spectroscopic methods, and usually finding them helpful. It should be remembered that application of such methods to industry is only beginning, and their full power can only be realized by detailed attention to such problems as are presented for solution.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

SOME EXPERIENCES OF THE USE OF SCALE MODELS IN GENERAL ENGINEERING.—Engineering, London, England, September 9, 1938.—(Extract from article by Richard W. Allen, C.B.E., M.Inst.C.E.)

Air Supply to Ships' Boiler Rooms.—Difficulties developed early in the present century in connection with the adequate supply of force-draught air for marine boiler rooms, resulting, in some cases, in ships being unable to secure smokeless combustion at full power, and arising from the failure to

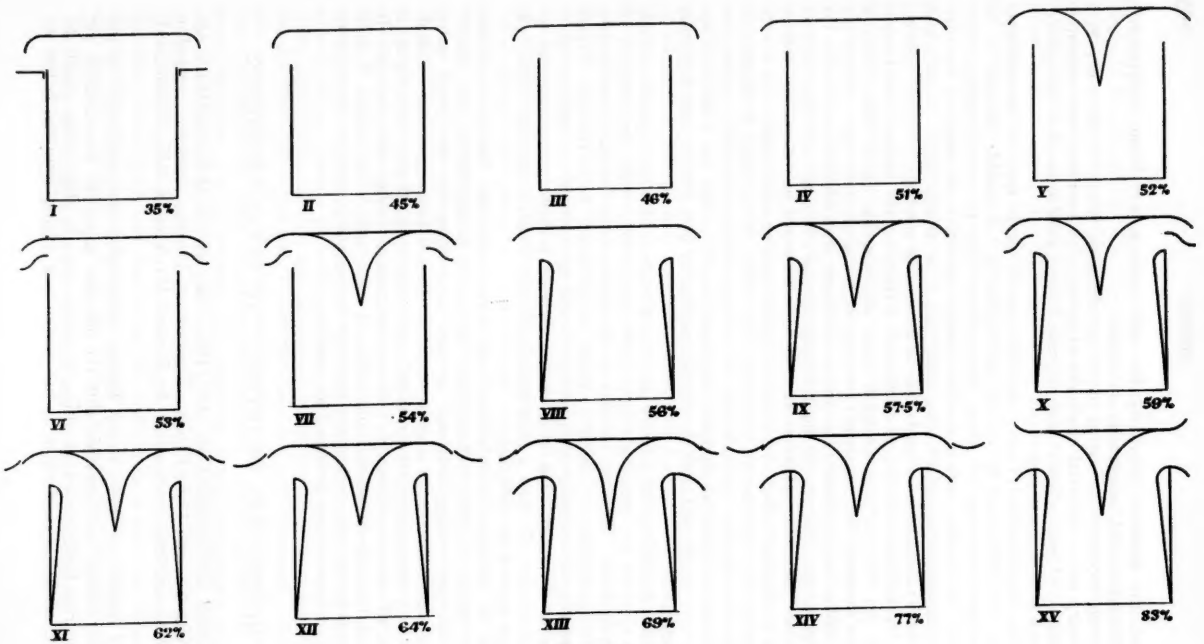
I 35%
II 45%
III 46%
IV 51%
V 52%
VI 53%
VII 54%
VIII 56%
IX 57·5%
X 59%
XI 62%
XII 64%
XIII 69%
XIV 77%
XV 83%

FIGURE 1.

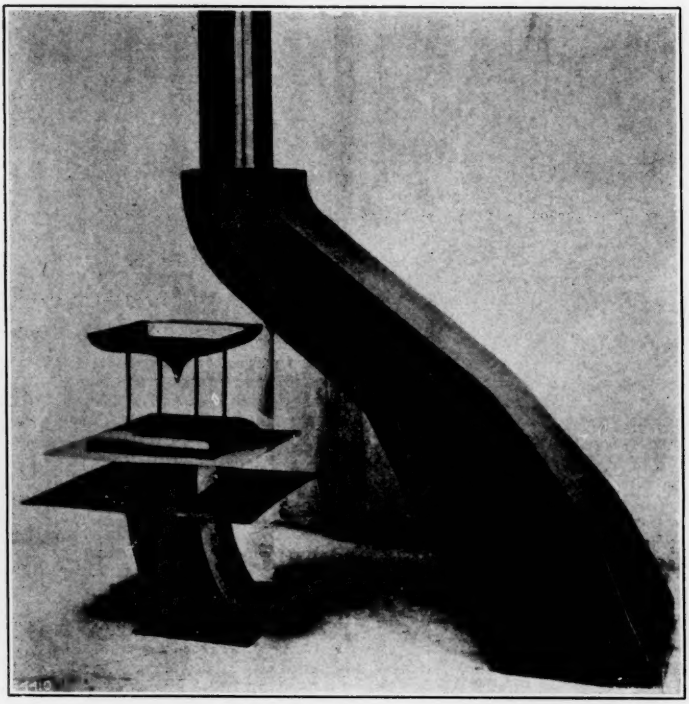

FIGURE 2.—MODEL OF AIR INTAKE AND FLUE-GAS UPTAKE.

maintain the required air pressure in the boiler rooms. It being known that the individual components of the air supply machinery were fully adequate to the boiler duties, an extensive investigation was carried out by the author into the design of forced-draught systems as a whole, when enormous and hitherto unsuspected losses were found to exist in the means then used for conveying and regulating the draught air. New standards were therefore developed experimentally for air speeds and passage shapes, and the streamline principle was applied extensively to the components, intake cowls and the like, while entirely new constructions were introduced for such elements. An example of this development work is illustrated in Figure 1, which shows diagrammatically the forms of fifteen different deck intake cowls that were tested by means of wood models made to a scale of approximately one-quarter of full size. The type of cowl in use prior to the experiments was that represented by item I of the figure, which was capable of admitting only 35 per cent of the air quantity that would pass through the same trunking under perfect entry conditions and making use of the same pressure drop. In item XV, the final and subsequently adopted pattern, this figure was raised to 83 per cent.

More recently, these investigations have been continued in great detail into the losses in a ship's air and flue-gas system as a whole, losses in both downtake and uptake passages being studied. These investigations, the objects of which were, firstly, the reduction of the frictional losses to a minimum and, secondly, the measurement of their exact value for purposes of forced-draught fan design, have been carried out by means of models, some of which are illustrated in Figure 2, one-eighth of the full sizes of the intakes, uptake galleries, their associated gratings, etc. An interesting point arises in connection with the testing of uptake passages over the question of scale effect. The gases leaving an actual furnace do so at a temperature of about 700 degrees F., whereas the model tests have to be carried out at atmospheric temperature. In spite of this difference in operating temperatures, the model test results are a more faithful copy than they would have been if carried out at 700 degrees F. The reason is that since the viscosity of a gas decreases as its temperature falls, the small passages of the model have, in accordance with the principle of dynamical similarity, a gas of decreased viscosity to deal with. True similarity would not, however, be obtained unless the temperature reduction were carried to —120 degrees F., but the only slightly more faithful results of such a test would not justify the greatly enhanced difficulty of carrying it out.

MARINE RADIO SERVICE.—RCA Review, New York, N. Y., July, 1938.—(Extract from article on The International Telecommunication Conference of Cairo, 1938, by C. B. Jolliffe.)

In the marine service particular attention was paid to improving the regulations having to do with general procedure within the mobile service and operations concerning calling and distress. The following paragraphs give some of the important results, but do not include many minor changes. The principal results regarding the marine services is the general clarification of all the articles relating to the service.

The United States had proposed the elimination of traffic on 500 kc other than for calling, distress, urgent, and safety messages. This was supported by a few nations, but strongly opposed by most of the large maritime nations

other than the United States. Under the new regulations in regions of heavy traffic ships may transmit only a single short message on 500 kc and coast stations are forbidden to use the frequency for traffic.

Since 1927 the United States has been endeavoring to eliminate spark transmitters. Under the provisions of the Madrid Treaty, spark transmitters with power greater than 300 watts are not permitted to operate after January 1, 1940. The exemption for these low-power spark transmitters was continued. However, their use was restricted to three frequencies, 375 kc for direction finding, 425 for traffic and 500 kc for distress calling. This restricts the interference which can be caused by this type of transmitter.

Two waves, 425 and 480 kc, were set up for use by Type A-2 transmitters, to be used only by ships in regions of heavy traffic in Europe. No European coast stations may use these frequencies.

A coast station in a region of heavy traffic may be assigned a calling wave which is separated from the general calling wave of 500 kc by not more than 5 kc. This is common practice in various parts of the world for the purpose of eliminating interference, but has not been in strict accord with regulations.

The band in which no transmission is permitted during the silent period was decreased from the old band 460-560 kc to 480-520 kc.

The frequency 1650 kc was set up as a distress wave for low-power radiotelephone stations in the European region, in addition to its use in that region as a calling frequency.

The provision that all ship stations compulsorily equipped with radio apparatus be able to transmit and receive on two frequencies besides 500 kc was required in the band 365-485.

The provision of the Madrid Regulations concerning the frequency meter on board a ship which has caused considerable confusion was clarified so as not to require a frequency meter if the circuits of the transmitter are such as to permit the maintenance of the frequency within the accuracy of one part in 5000.

GRADING WELDERS.—Power, New York, N. Y., July, 1938.—(From an article by D. H. Cory.)

The arcronograph, highly developed electrical recording meter, can be used to supplement usual physical tests in welding-operator qualification.

The Detroit Edison Company began rebuilding Conners Creek in 1933. That year also marked the adoption of arc-welded joints by the company for piping systems operating at high pressure and high temperature. Throughout that rebuilding program and the subsequent installation of new generating equipment in Delray No. 3, arcronographs * have been used as an inspection aid in welding all field piping joints for severe-service conditions.

To acquire experience in interpreting arcronograph charts, further use was made of these instruments for all experimental and operator-qualification test welds. Since all such welds are subjected to destructive tests in determining physical properties, including soundness, this practice offered opportunity for correlation between weld properties and arcronograph charts which could not be had in regular field construction.

* For a description of the instrument, and a discussion of the theory upon which it operates, see "The Evolution of the Arcronograph," by Bela Ronay, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, August, 1934.

TABLE I — PHYSICAL PROPERTIES OF WELDS

Weld	Tensile Tests		Bend Tests	Nick-Break Tests			Time for Making Joint Hours
	Yield Point lb sq in.	Ultimate Strength lb sq in.	Elongation of Outer Fibres, Per Cent	Number of Slag Inclusions	No. of Visible Defects Per sq in.	No. of Visible Defects Over $\frac{1}{16}$ in. dia	
A	43,700	74,500	46	0	1	0	
	50,800	72,800		0	3	0	8
	41,000	74,450	49	0	1	0	
Avg	45,200	73,900	48				
B	43,800	72,800	57	0	2	0	
	50,400	63,400		0	10	0	20
	43,400	70,600	57	0	4	1	
Avg	45,900	68,900	57				
C	40,100	71,800	46	1 ($\frac{1}{16}$ in. long)	7	1	
	41,700	72,600		0	7	0	12
	46,500	70,300	50	1 ($\frac{3}{16}$ in. long)	5	2	
Avg	42,800	71,600	48				

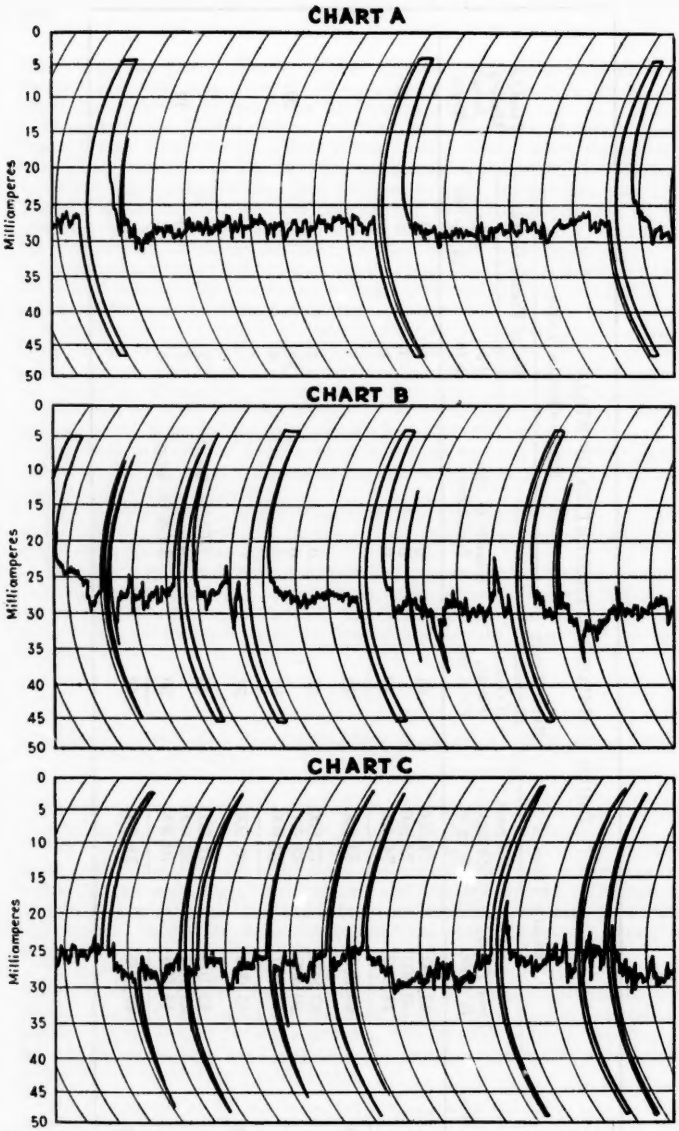

FIGURE 1.—THREE CHART RECORDS INDICATE DEGREE OF WELD SOUNDNESS: A, GOOD WELDING; B, SPOTTY; C, POOR QUALITY.

From experience thus gained, we believe that arcronographs can be used to advantage in classifying welders. We have noticed a striking difference in the appearance of charts produced by welders whose welds meet the requirements of the qualification test as to physical properties, and of those whose welds do not meet the requirements.

The three sections of charts shown are from three welds, each made by a different operator. Each chart section is representative of the entire chart from which it was taken. Chart "A" is typical of a sound weld for the brand of electrodes used. Deposition of two complete electrodes and parts of two others is shown, the three full-scale deflections being interruptions for changing electrodes. Chart "B" is marked by a succession of "starts and stops," with short intervals of satisfactory welding. Chart "C" is extremely ragged, with even shorter intervals of sound welding.

Physical properties of the three welds are shown in Table I. It will be noted that all welds were satisfactory from the standpoint of strength and ductility. However, only "A" was satisfactory from the standpoint of soundness. It has been our experience that defects ordinarily encountered in welds made under a carefully controlled procedure are not of sufficient size to affect the tensile or bend properties under static loading. Soundness tests appear to be the best basis for judging comparative skill among a group of welders. A correlation between the three arcronograph records and the soundness tests is apparent. This correlation exists, even though each layer of deposited weld metal of all three welds was thoroughly cleaned and all visible defects removed.

No record is available of the distribution of total elapsed time required to make each joint as between welding time and cleaning time, but we feel sure, from extended observation, that much of the excess time spent in completing the "B" and "C" welds was consumed in chipping out defective work. Had the same amount of time been devoted to the "cleaning" of each weld, the correlation between the arcronograph records and the soundness tests would have been more striking.

NOT A SUBSTITUTE.

This discussion is not to be interpreted as a proposal to substitute the acronograph for physical-property tests in the qualification of welding operators. The purpose is simply to point out that, in the experience of the author's company, the arcronograph has been found a useful aid in classifying welders' ability to produce sound welds under field conditions.

Simple recording meters, either ammeters or voltmeters, have not given as satisfactory results. Such meters respond to incorrect welding conditions, such as an unduly long or short arc, only in proportion to the actual change in arc current or voltage. The arcronograph, however, exaggerates defects by giving a full-scale deflection whenever welding conditions are not within predetermied limits, fixed by relay settings. Furthermore, the recording ammeter or voltmeter, unless supplemented with auxiliary equipment, produces a continuous chart throughout the day. Under field-welding conditions, only a small part of the elapsed time devoted to a joint is spent in actually depositing weld metal. Thus the provision whereby the arcronograph is operative only during actual welding, reduces greatly the amount of chart to be handled.

VIBRATION IN SHIPS.—Shipbuilding and Shipping Record, London, England, September 8, 1958.—(Extract from a paper by M. Costantini, B.Sc.)

The natural frequency of structural hull vibration may be estimated. By avoiding synchronism between these frequencies and those of the disturbing forces (usually the first or second order unbalanced forces or moments of the main engines) vibration may, sometimes, be prevented.

The predetermination of "local" critical frequencies is, needless to say, a practical impossibility, and therefore the prevention of this kind of trouble is also a matter of pure chance. The diminution of vibration by "prevention" seems, therefore, almost hopeless. Granted that some kind of vibration must unavoidably be present, what are the means at the disposal of the designer for minimizing its unpleasant effects?

1.—Special attention should be given to the balancing not only of the primary, but also of the secondary and higher order forces and moments of all reciprocating machinery; by keeping the free forces and moments as small as possible, even though synchronism should occur, the resulting amplitude of vibration will be small and the "critical" range short, a change of two or three revolutions being sufficient to make vibration disappear altogether.

2.—The most accurate balancing is useless to prevent vibration unless combined with a rigid engine. In an engine with flexible framing, each cylinder will act on its own and set up vibration. Although motors have been generally improved in this respect in recent years (thanks also to the action taken by shipbuilders who refused to supply under the name of "seatings" something which, by rights, should have formed part of the engine bedplate), a few more tons of cast iron judiciously distributed over the engine framing would be well worth the little extra money.

3.—Motor-car designers, who are apparently more keenly concerned to keep down vibration than their marine confreres, have realized long ago that the point of support of reciprocating machinery should be situated, to minimize vibration, at the point where the least motion due to internal forces takes place, *i.e.*, at about mid-depth of the engine, and that the satisfactory results thus obtained could be further improvd by placing the engines on elastic supports. Small Diesel motors may cause a good deal of annoyance in a ship, and yet elastic supports are only now beginning to make a timid appearance on board ship.

4.—So far as the average passenger is concerned, half the discomfort caused by vibration is due to rattling. Here again, the motor-car designer could teach something to the shipbuilder. The cheapest car, at least when new, is rattleproof; why some of the simple devices, so successfully used on cars to eliminate noises, could not be used on luxury liners, where doors, beds, glasses, etc., continue undisturbed their noisy protests, is a mystery which still remains to be solved.

5.—Local vibration, when confined to isolated portions of decks between pillars, can be easily eliminated by extra pillaring or local stiffening, or even ballasting; when the pillars themselves vibrate, the cure becomes more difficult, and in many cases impossible. The fitting of complete 'tween-deck bulkheads or the substitution of a pillar by a strong beam or girder has proved fairly effective.

6.—A form of local vibration, against which one is practically helpless, is that set up by the propellers. The free forces resulting from the difference in loading between the inboard and outboard blades, owing to the difference in wake distribution, may become so great in high-powered ships (several tons) that severe vibration unavoidably follows, irrespective of synchronism.

Inboard turning propellers are worse in this respect than outboard turning, as the effect of the ascending wake is added to instead of being substracted from the effect of the forward component of the wake. By removing the propellers farther away from the ship's sides, in twin screw vessels, the wake difference over the propeller area may be reduced, and consequently also the free forces giving rise to vibration, but the small advantage eventually gained must be rather dearly paid for by the resulting loss of propulsive efficiency. Careful designing and streamlining of after-end and bossing, by reducing eddying and turbulence, will certainly prove beneficial also in respect of vibration.

DREAMS OF COLD LIGHT BECOME REALITIES.—The Frontier, June, 1938. Published by the Research Foundation of the Armour Institute of Technology, Chicago, Ill.

When primitive man first tamed fire and bent its stubborn nature to his service, he found in it a source of two beneficent qualities—warmth and radiance—two qualities which to his dim perception must have seemed inextricably mingled. He knew no way of generating light, save through the production of heat.

The scientists of a later day were to draw the distinction his mind could at best have only imperfectly grasped—the line which separates the natures of heat and light. But they, too, with their clearer knowledge, found themselves equally incapable of directly generating light. They devised ever more efficient methods of producing from a source of heat an adequate quantity of light. The discovery of new metals, the perfection of evacuating equipment, the knowledge of the properties of inert gases placed at their command temperatures previously unattainable. White-hot tungsten in a vacuum bulb supplanted the glowing embers of a wood fire—with a tremendous increase in the quantity of light produced. But there was still no fundamental change in the method of generating light. It remained a by-product of heat. In every light-giving device, the major share of the energy consumed was wasted in unwanted heat; only a small fraction was converted into light.

Scientists turned their attention to the basic problem of generating light as light, not merely as the inevitable concomitant of heat. For years they pursued the dream of "cold light"—a dream as elusive as its prototype, the will-o'-the-wisp. In the realization of that dream there lay the possibility of enormous savings in energy through the truly efficient production of light.

And the dream of the research scientists has at last become a reality—a partial reality only, it is true, for the light which they have at last produced may not be "cold." But it is certainly far cooler than any previous source, far more effective in its conversion of electrical energy into light.

"Fluorescent lumiline lamps" is the name applied to the new source of cool light, which was developed by research workers in the Nela Park laboratories of General Electric. Simultaneous production of the new lamps is announced at the Bloomfield works of Westinghouse.

Scientists reached the apparently unattainable goal of cold light by a radically new method, first converting the electrical energy into invisible light, which can be generated with little waste heat, then changing the invisible rays into visible ones.

In a lamp tubular in form electrical energy produces a low-pressure mercury vapor discharge—high in ultraviolet rays, low in radiation of visible

light and heat. The inner surface of the tube is coated with fluorescent chemicals, which glow brilliantly as the invisible ultra-violet rays impinge upon them, generating a copious quantity of visible light with the smallest amount of heat yet attained.

With the realization of the scientists' dream comes the promise of potential savings in energy consumption for lighting purposes—savings which may be made in every factory and home. These savings may still be in the future for the average user of light; the new lamps cannot, of course, be substituted for present types without change of fixtures. But in spite of their different construction, the new lamps are simple and easy to mount. The incidental problems involved in their installation are a minor affair compared to the tremendous stride which the scientists have made toward higher lighting efficiency.

GROOVED BOILER TUBES.—Combustion, New York, N. Y., July, 1938.

According to an article by R. Schulze in "Die Wärme" of March 12, a new type of grooved boiler tube has been developed by the Mannesmannröhren-Werke in Germany. A spiral groove is cold-rolled on the outside of a seamless tube to a depth of about 3/16 of an inch and about ¼-inch pitch. The tube is then heat treated. The heat transmission, as indicated by tests quoted, is about 30 per cent greater than that of a plain tube of equal diameter because of the greater exposed surface and it is claimed that the mechanical qualities are equal to those of the plain tubes. The grooved tubes can be bent, expanded or welded in the same manner as plain tubes and are being made for boilers, superheaters and economizers, particularly those of the steaming type.

AIRSCREWS OPPOSITELY-ROTATING.—The Aeroplane, London, England, August 17, 1938.

Fortunately, so far as keeping up our interest in Aviation is concerned, the solution of one problem in aeronautics practically always leads up to the appearance of even more difficult problems to be solved. The arrival of the controllable-pitch airscrew seemed to have solved so many problems in such a satisfactory way that one was rather apt to feel that the airscrew was not going to worry us very much in the future. Actually problems relating to the airscrew are very much the limiting factor in the design of high-performance modern aeroplanes.

In Military Aviation, for instance, the size of human beings remains the same, but the power of the motors available to drag or push them through the air increases. Thus the size of aeroplane remains much about the same, but the power of the motor increases. A direct result of this is a tendency for aeroplanes to have airscrews of larger diameter. An interesting curve bringing this out was shown by Mr. George Mead of the United Aircraft Corporation in his lecture before the Royal Aeronautical Society on April 22, 1937. Naturally there will come a time when one will have to increase the number of blades and so reduce the diameter.

Meantime the problem of torque is becoming serious. Torque is the reaction to the rotation of the airscrew. If one regards the blades of the

airscrew as wings, then the torque is equivalent to the drag of such wings. Broadly speaking, one may say that the torque increases with the speed of the aeroplane and the power of the motors.

The effect of torque on the aeroplane is to cause it to swing while taking off and to hamper its maneuverability in the air. A somewhat similar effect used to be a big problem in the early days. Many of the war-time single-seat fighters with rotary motors owed their peculiar habits to a similar effect caused by the rotation of the motor, complicated by its gyroscopic effects.

Oppositely-rotating airscrews are already in service. Many of the modern French twin-motor bombers, for instance, have oppositely-rotating airscrews, but they are not concentric. That is, they are not on the same axis. The arrangement is to improve control by making the wing-motors revolve in opposite directions. An objection to the scheme is that it multiplies spares.

We have already said quite a lot in "The Aeroplane" about the new fighter which Mr. Frits Koolhoven has been developing in Holland with oppositely-rotating airscrews. Also a good many people in this country have seen on the news films pictures of the new American Curtiss fighter which has been provided with two oppositely-rotating airscrews for experimental purposes.

The first machine to appear with this arrangement in recent years and to make a successful showing was the Italian Macchi-Castoldi racer with the two Fiat aero-motors which, coupled together, give 3100 H.P. This machine still holds the Absolute Speed Record of 440 M.P.H. One can probably safely say that this arrangement was not primarily selected because of considerations of torque, but as the only possible means of getting so much horsepower into the frontal area of a single 1600 H.P. Fiat motor.

As the two motors had separate crankshafts, the designer probably thought he might as well couple each to an oppositely-rotating airscrew as to try and couple them both to the same airscrew. In any event the diameter of the airscrew would then be so large that there would have been some difficulty in getting the adequate clearance between the blades and the water.

The effect of torque was no doubt in his mind, and helped to influence his decision. Actually, the floats of the Supermarine S.6 could not have been made any smaller, because the enormous torque of the motor called for a considerable amount of reserve buoyancy, or the starboard float would have been forced under water when the motor was opened up.

So far designers have probably been fairly fortunate. Considerations other than those of torque have made necessary the provision of such wing-area as to make the span large enough to counter any trouble from torque. Nevertheless, as we try to cram more and more power into smaller aeroplanes, particularly such high-performance machines as fighters, we are quite definitely going to get up against this problem of torque. In fact, one or two existing designs are already very close to the limit so far as being able to steer straight on the ground before taking off is concerned.

Quite apart from this question of torque, another difficulty arises in connection with the development of really big areo-motors of, say 4000 H.P.; the trouble is then to limit the airscrew to a reasonable diameter. The obvious solution is to use more blades. This is not so easy when one has to make the airscrew not only multi-bladed, but also to have controllable-pitch mechanism. Torque would still be a problem.

On the other hand, if one provides two airscrews to absorb that amount of power, and makes them run in opposite directions, then one reduces the diameter and the torque together.

Summing up his paper on "Luftschrauben für schnelle Flugzeuge" (Airscrews for Fast Aeroplanes) from the "Jahrbuch 1937 Der Deutschen Luft-

fahrtforschung," Professor Dr. Ing. Weinig has some interesting remarks to make. He definitely favors the close-coupled tandem arrangement of opposite-rotating airscrews and produces figures to support his argument that with this arrangement a single-seat fighter should be some 25 M.P.H. faster than the equivalent with two motors.

A possible way to save weight and trouble would be to mount the airscrew shaft and its reduction gear on a separate mounting in the nose of the aeroplane.. The crankshafts of the motors would thus only have to carry the over-running clutch gear. Such a scheme works well in ships. The turbines are coupled in the engine-room to the propeller shafting.

Another interesting point about this development is that nobody has so far faced up to the question of using controllable-pitch airscrews in such combination. Will both have to change pitch at once in opposite directions? What will happen if only one screw changes pitch at a time?

ENGINEERING RESEARCH IN THE ROYAL NAVAL COLLEGE, GREENWICH. MAY, 1938.—Journal of the Institution of Civil Engineers, London, England, No. 7, 1937-1938.

Although a number of the subjects investigated experimentally and analytically in the Engineering Laboratory in the Department of Applied Mechanics under the direction of Professor B. P. Haigh, M.B.E., D.Sc., are of specialized Naval interest, other subjects of more general interest are mentioned in the following notes:

WELDING RESEARCH.

Earlier investigations carried out in the Laboratory were directed towards the development of optimum designs for right-angled and oblique joints between rolled sections and composite sections in general use in shipbuilding and in structural engineering, and to the comparison of such welded joints with standard riveted constructions. This work has been extended in different directions, and notably to the development of optimum designs for oblique branch connections and anchored bends in high-pressure pipe-lines. Throughout these investigations, the use of resin has been developed for revealing the distribution of strain in the structures, and this method appears to be effective in revealing the gradual spreading of plastic strain under increasing load or pressure.

FATIGUE OF METALS.

Fatigue cracking in welded and in riveted joints is being investigated in a large Haigh fatigue-testing machine that works with a range of load of 6 tons and at a frequency of over 4 million cycles per working day of 24 hours. A smaller machine of the same type is being used in connection with other researches, on the fatigue strength of wire ropes with different forms of end fastening, and on the fatigue of lead and different lead alloys as used in pipes and in electric cable sheathings. It was in this same fatigue machine that corrosion-fatigue was first investigated in 1916, the special dangers of conjoint chemical and mechanical action being then revealed in connection with vibration of steel and other metals immersed in sea water in particular. Lead is remarkable in respect that fatigue is delayed when the surface of the specimen is moistened with water during the test, or when the specimen is totally

immersed in water, or even in acids that accelerated chemical attack. A Haigh-Robertson bending-fatigue machine is being used in researches on the corrosion-fatigue resistance of different types of cold-drawn rustless steel. In this machine, the long thin test-piece in the form of a rod or wire is flexed by an axial load and is rotated at a very high speed, imposing as many as 14 million cycles or more per day. The same machine, modified in certain details, is used also in testing copper and cadmium-copper trolley wires of large sections, either round or of figure-8 profile.

PLASTIC YIELD AND CRACKING.

Plastic yield in mild steel is being investigated by extending to tensile tests precautions comparable with those more generally observed in fatigue testing. The test-pieces are formed with enlarged ends and generous transition curves to eliminate the local concentrations of stress that are generally disregarded in tensile testing, and are loaded through knife edges arranged to ensure truly axial loading without bending stresses. It is found that the limit of elastic proportionality can be raised, in many normalized or "as received" samples, to a value approaching or even exceeding the ultimate tensile strength of the mild steel. The high value of this initial yield point ("higher yield point") appears to explain many anomalies that have been observed in practical experience. The lower yield point that is observed immediately plastic yield has commenced is being investigated in a variety of mild steels suitable for different applications, and is considered to afford a serviceable and exceedingly reliable basis for structural design. Cracking in ductile metals is being investigated, not only in relation to fatigue, but also under complex stresses approximating to "triple-tensile." Novel forms of notched test-piece, admitting of precise calculation, are employed in cracking tests; and other novel forms are employed for producing "triple-tensile" stress resulting in brittle fracture with little or no plastic deformation even in ductile metals. Thermal contraction is being investigated in particular as a cause of triple-tensile stress resulting in brittle fracture.

OTHER RESEARCHES.

Light alloys suitable for use in engine pistons are being tested in different ways, including fatigue, and an engine is being arranged for investigating torsional vibration, particularly in camshafts affected by the action of tappets and springs. The collapse of pipes under external pressure is being investigated analytically and experimentally with particular reference to the effect of slight deviations from truly circular profile. A novel form of wind-tunnel, specially designed to give a stream of uniform pressure and speed through the working chamber, is being employed in conjunction with an original design of weighing balance in a variety of problems arising in practice. Lubrication and viscosity are also being investigated analytically and experimentally.

The researches indicated are being carried out by students working in association with Professor B. P. Haigh, Assistant Professor F. W. Thorne, Mr. T. S. Robertson, and Mr. C. H. Helmer.

DISCUSSIONS AND COMMENTS.

The value of technical articles is greatly enhanced by discussion and comment. In the future the JOURNAL will provide a forum for this purpose. Suitable matter for publication is invited.

BOOK REVIEWS.

PRACTICAL SHELL DEVELOPING FOR STEEL SHIPBUILDERS. By Adam F. Tulin. Simmons-Boardman Publishing Company, New York. $3.00. Reviewed by Lieutenant Commander J. M. Kiernan, (CC) U. S. Navy.

In the days of wooden ships and iron men, the ship designer first prepared a model of the vessel which he was commissioned to design, and more often than not to build. With a solid piece of soft wood, he would whittle here and there, until he finally had a shape of hull which was pleasing to the eye, and gave the least resistance to propulsion in accordance with the practice of the day. From this model, he would lift the offsets and lay them out on the scrieve board. It was here that we find the first application of ship form development. From the scrieve board, the developed offsets were laid down to full scale on the mold loft floor. As may be expected, because of scale effect, hard spots or unfaired lines were found, requiring further development or fairing in on the loft floor. The old-time shipwright used the lines on the mold loft floor to "get out" his frame and bevelled templates. With the passing of the wooden vessel, the mold loft began to take on an increasing importance, until today it ranks next to the drafting room in the shipbuilding yard.

Many books and theses have been written on mold loft practices. A review of them would show that in the majority of cases, they were written by a Naval architect who tried to cover the entire field, with the usual result that the practical man, with his limited knowledge of descriptive geometry, could not comprehend all that the various authors gave. "Practical Ship Developing," by Tulin, is a practical man's book in that no theory is given. The author states that "The principle of triangulation is used in some of the problems. It can be applied wherever it is found necessary . . ." The reader is told how and not why.

To others than practical shipbuilders the value of the book might be improved by adding a chapter on the basic fundamentals of tri-

angulation. Also a glossary of the terms and a description of the practices of the mold loft would be instructive. To the library of the shipfitter and loftsman, this book should be a most welcome addition. Its examples are clearly stated and most easily followed. The number of examples cover all that are likely to occur in the construction of the average type of vessel. For the student of shipbuilding, the book is recommended in connection with his mold loft work.

THEORY OF MECHANICAL REFRIGERATION. By N. R. Sparks. McGraw Hill Book Company, New York. $3.00. Reviewed by Henry E. Bethon.

This book deals with the theory and application of mechanical refrigeration in all practicable aspects. The text is well presented, starting first with the basic fundamental principles of thermodynamics and of refrigeration, then branching out to a broad discussion of the various systems of mechanical refrigeration that have been established on a practical basis. Through the medium of numerous problems, the application of the fundamentals of refrigeration is amply demonstrated. The treatment of various refrigeration cycles and of the thermodynamic formulas involved therein has been thoroughly undertaken.

Because of the widespread use of the refrigerant FREON-12, resulting from its favorable characteristics and safety features, it is suggested that in the next edition the text be supplemented by including tables and charts outlining the thermodynamic properties of this refrigerant in addition to the data already given for ammonia and carbon dioxide.

In my opinion, this book should be highly endorsed as an excellent text in the field of mechanical refrigeration.

ASSOCIATION NOTES.

ANNUAL MEETING.

The Annual Meeting of the Society was held in the Navy Department at Washington, D. C., on Tuesday, 4 October, 1938. The meeting was particularly well attended.

The following were placed in nomination for officers for the calendar year, 1939:

For President:

Rear Admiral S. M. Robinson, U. S. N.

For Secretary Treasurer:

Commander William E. Malloy, U. S. N.
Lieut. Commander Guy Chadwick, U. S. N.

For Member of Council:

Captain Bryson Bruce, U. S. N.
Captain Sidney M. Kraus, U. S. N.
Captain J. M. Irish, U. S. N.
Captain H. Gordon Donald, U. S. N.
Commander R. R. Thompson, U. S. N.
Commander Charles W. Styer, U. S. N.
Lieut. Commander J. B. Dow, U. S. N.
Captain J. A. Furer (CC), U. S. N.
Commander E. L. Cochrane (CC), U. S. N.
Commander C. J. Odend'hal, U. S. C. G.
Commander Ellis Reed-Hill, U. S. C. G.
Mr. Philip N. Israel.
Mr. George B. Ferrier.
Mr. Howard J. Ball.
Mr. A. F. E. Horn.
Mr. Roland Whitehurst.
Mr. Karl D. Williams.

Ballots have been distributed. Polls close at 4:15 on 26 December, 1938.

It was decided to hold the Annual Banquet as usual in the year 1939. The date and other details will be announced in the near future.

MEMBERSHIP.

The following have joined the Society since the publication of the August, 1938, JOURNAL:

NAVAL.

Carlson, E. V., Lieutenant, U. S. Coast Guard.

Columbus, C. E., Lieutenant, U. S. Coast Guard.

Oren, John B., Lieutenant(jg), U. S. Coast Guard.

Stow, James P., III, Ensign, U. S. Coast Guard.

Varney, Newell F., Lieutenant, U. S. Navy.

CIVIL.

Goldsmith, Lester M., Chief Engineer, Atlantic Refining Co., 260 South Broad St., Philadelphia, Pa.

Hammond, Harry B., Rockbestos Products Corporation, 5942 Grand Central Terminal Building, New York, N. Y.

Kennedy, John J., Engineer, Ingersoll-Rand Co., 1627 K St., N. W., Washington, D. C.

ASSOCIATE.

Armstrong, Harold O., 1346 Bradley Road, West Dover, Ohio.

Cortes, René, Commander Engineer, Chilean Navy, Club Naval, Valparaiso, Chile.

Droescher, L. A., care C. H. Wheeler Mfg. Co., Lehigh and Sedgley Ave., Philadelphia, Pa.

Gimenez-Figueroa, Manuel, Lieutenant, Argentine Navy, 856 Massachusetts Ave., Cambridge, Mass.

Marin, Antonio, Lieutenant, Argentine Navy, 420 Memorial Drive, Cambridge, Mass.